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DARLINGTON ANNULUS GAS MOISTURE INJECTION TESTS

Report No. 90-298-K

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ABSTRACT

Moisture (D_2O) injection tests were carried out on the CO_2 Annulus Gas System at Darlington NGS, Unit 2 to determine the dynamic response of the AGS piping and dew point meters. The station dew point meters read low during the tests by about 5 to 10 degrees as compared to Research Division meters although the station meters had been calibrated with heavy water. The advantage of using concentration versus time curves in addition to dew point versus time in the estimation of leak rate and leak location is discussed.

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ontario hydro research division

EXECUTIVE SUMMARY

Report No. 90-298-K
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The Annulus Gas System (AGS) is designed to reduce heat loss from the primary heat transport system to the moderator and has gained importance in the detection of heavy water leaks from pressure tubes. In newer stations, alarms are triggered if the rate of rise of dew point as measured by Panametrics dew point meters exceeds a pre-determined value.

A model predicting the dew point response of the AGS in the event of a water leak was developed by Nuclear Engineering Department and moisture injection tests were carried out on Unit 2 at Pickering NGS in 1987 to confirm the predictions of the model for the Pickering design. These tests were repeated for the Darlington design in 1989 as part of the Unit 2 commissioning program and the information gathered is reported herein.

Heavy water, in vapor form, was injected with the reactor initially cold then hot at known rates. Injection was into several locations in the AGS including strings containing four, eleven and twelve channels in series. Although the station meters were calibrated with D₂O as previously recommended, they gave low readings as compared to the three types of meters supplied by Research Division. These latter performed well especially at high dew point near the end of the injection period where heavy water predominated. A recalibration of the in-station meters has since been completed.

As expected, light water predominated in the AGS after a pure CO₂ purge due to the small amount of light water in the CO₂ gas supply. Following the purge, the system dew point increased slowly for the hot tests only; the results indicate that heavy water was appearing in the recirculated gas at about 0.8 g/h prior to the commencement of injection. It is not known if this was a result of desorbed moisture from the walls of the system and/or deuterium ingress into the system through end fittings or some other source.

The MCM silicon sensor was the only instrument giving an accurate indication of the amount of water present when both light and heavy water existed in the AGS and this was in terms of concentration.

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Concentration versus time curves were linear after the initial period of step changes in the AGS response. The slope of the curve was proportional to the simulated leak rate. Hence, an increase in the slope of a concentration versus time curve during a leak would indicate an increase in the leak rate. However, at the start of a leak, the dew point indication was the more sensitive parameter.

Accurately calibrated MCM and Panametrics hygrometers in series can be used to rapidly indicate whether light water or heavy water species predominate in the AGS, i.e., the presence of an end shield cooling leak. This would provide a quicker response since the present cold finger method is slow at dew points below -15°C .

As expected, the delay time for appearance of the injected water increased with string length. The delay time was shorter for a hot reactor than for a cold reactor probably as a result of a higher velocity in the annuli. The delay time for single pass operation, i.e., no gas recirculation as occurs during purge operation, increased as operating pressure increased at the same mass flow rate of the purge CO_2 gas. Hence, pressure measurement or control during purges are desirable.

The slope of the concentration versus time curve during the initial response (initial slope) increased with increased reactor temperature probably as a result of increased volumetric flow rate at high temperature and also reduced adsorption of water on the system walls. It also increased with reducing string length especially for a cold reactor. The final slope which occurred a few hours after the start of the simulated leak, was proportional to the simulated leak rate and was independent of reactor temperature. As stated above, the final slope of the concentration versus time curve during operation would indicate the magnitude of a leak.

The data indicated that the approximate location of a leak could be determined from the concentration versus time curves. For example, the larger the ratio of the initial slope to the final slope, the closer the leak was to the end of a string. Similarly, the times at which various events occurred could be used to obtain information on the leak location.

Recommendations are made for future tests to improve the accuracy and frequency of data collection and to recalibrate AGS flow meters.

VA [signature]

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To Mr. D.W.Souther
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DARLINGTON ANNULUS GAS MOISTURE INJECTION TESTS

1.0 INTRODUCTION

The Annulus Gas System (AGS) at Darlington NGS utilizes carbon dioxide gas in the annular space between the pressure tubes and calandria tubes to reduce heat loss to the moderator. Moisture leaking to the annulus gas from pressure tubes, calandria tubes and end shields are detected by Panametrics aluminum oxide dew point meters.

Leak simulation tests were carried out at Pickering unit 2 in 1987 by injecting heavy water vapor into the AGS/Singh and Chang (1988). The objective was to determine the response of that particular arrangement of AGS system piping and for dew point meters which were calibrated with light water. These tests were repeated in 1989 for the different piping design of Darlington NGS and for dew point meters calibrated with heavy water; the results are given in this report.

2.0 SYSTEM RESPONSE TESTS DESCRIPTION

A flow diagram of the AGS at Darlington is given in Figure 1.

As shown in Table 1, five initial tests were carried out with the reactor cold. This provided the opportunity to check the vapor injection equipment and procedure prior to the following seven tests on a hot AGS system. Other than the small amount of light water introduced with the bulk carbon dioxide during purge operations, all vapor injections were carried out with heavy water.

Initial objectives called for five and ten gram per hour injections until the system dew point exceeded -10°C (the term dew point is used instead of frost point below the melting point temperature for convenience). However, some tests (7, 11 and 12) at ten grams per hour were deleted and injection rates for single compressor operation were reduced because condensation would occur outside the feeder cabinet area in the string under test.

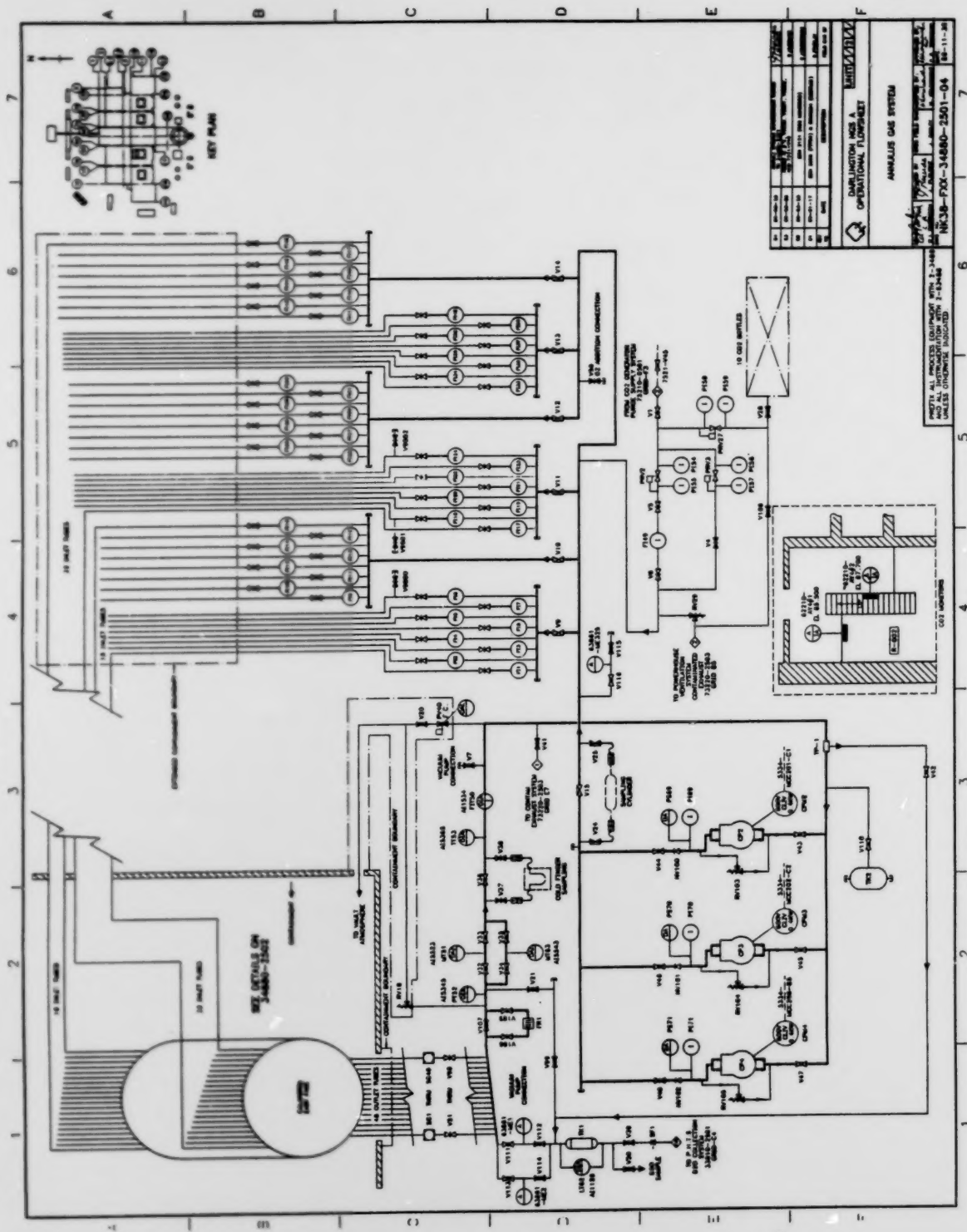


FIGURE 1
ANNULUS GAS SYSTEM

TABLE 1 SUMMARY OF TEST PARAMETERS

TEST NUMBER	INJECTION LOCATION	PRIMARY HEAT TRANSPORT CONDITION	AGS OPERATING MODE	D2O INJECTION RATE (G/HR)	COMMENTS	
1	EXTERNAL CIRCUIT V24 SAMPLING LOCATION R2-002 87.7M	COLD DEPRESSURIZED	2 CP RECIRCULATION AT NORMAL STRING FLOW RATES	11.2 TO 10.4 10.8 AVG	DEMONSTRATES OVERALL SYSTEM RESPONSE	EFFECT OF COLD VS HOT REACTOR FOR EXTERNAL INJECTION
6		HOT PRESSURIZED		10.4 TO 10.2 10.3 AVG		
3	4 CHANNEL STRING F118 V9001 R2-121 100M	COLD	2 CP RECIRCULATION	5.2 TO 4.95 5.1 AVG	EFFECT OF COLD VS HOT REACTOR	EFFECT OF RECIRCULATION FLOW RATE ON RESPONSE TIME
8		HOT	2 CP RECIRCULATION	4.5		
9		HOT	1 CP RECIRCULATION LOW STRING FLOW	2.3		
4	11 CHANNEL STRING F18 V9000 R2-121 100M	COLD	2 CP RECIRCULATION	5.05 TO 4.90 4.95 AVG	EFFECT OF COLD VS HOT REACTOR	TESTS 3, 4 & 5 SHOW EFFECT OF NUMBER OF CHANNELS TESTS 8, 10 & 13 SHOW EFFECT OF NUMBER OF CHANNELS
10		HOT	2 CP RECIRCULATION	4.5		
5	12 CHANNEL STRING F124 V9002 R2-121 100M	COLD	2 CP RECIRCULATION	5.3 TO 4.8 5.05 AVG	EFFECT OF COLD VS HOT REACTOR	EFFECT OF RECIRCULATION FLOW RATE ON RESPONSE TIME
13		HOT	2 CP RECIRCULATION	4.5		
14		HOT	1 CP RECIRCULATION	2.3		
2		COLD	CONSTANT PURGE SINGLE PASS	4.8		WITH TEST 5 GIVES EFFECT OF SINGLE PASS
15		HOT	CONSTANT PURGE SINGLE PASS	3.4		

NOTE: TESTS 7, 11 AND 12 CANCELLED

Injection into the main AGS header upstream of the distribution tubes was carried out to determine the overall system response. The other three injection points were directly into the 3/8 inch tubing at the inlets of a 4, 11 and 12 channel string. This produced the slowest dew point response times. The 4 and 12 channel strings represented the shortest and longest strings in the AGS construction and the specific strings chosen had the longest inlet and outlet tubing runs. Comparison of the responses of the 11 and 12 channel string was expected to yield information as to the response characteristics of a single channel.

3.0 TEST EQUIPMENT AND PROCEDURE

3.1 Injection Equipment for Dew Point Response

The equipment used for the heavy water vapor injections is shown in Figure 2. Bone dry carbon dioxide was metered by a mass flow controller and saturated with heavy water in a 30 cm diameter x 45 cm high aluminum vessel. Downstream of the saturator, the line was electrically heat traced and kept at a temperature of 50°C or greater to prevent condensation. Downstream of the sampling location was a three way valve used for injection or standby operation, during which it was possible to check the flow rate with a soap bubble flow meter or carry out moisture injection rate tests. The injection pressure gauge (Figure 2) was used to measure system pressure such that the saturator pressure could be matched on standby. This reduced pressure surges on switching from standby to injection.

A low carbon dioxide flow rate was used to reduce the amount of AGS pressurization since the AGS leak rate was reported to be about 0.25 standard L/min. At the start of injection into a string, the inlet rotameter needle valve was throttled to keep the combined injection flow and throttled flow equal to the flow through the string before injection. The water injection rate could be varied by varying the gas flow rate and the saturator temperature. In later tests, the saturator temperature was gradually increased as time went by and the system pressure went up to maintain the same mass input rate of water.

Tests in the laboratory showed that the saturator was 100% efficient. During the in-station tests, a small sample stream (215 mL/min) was diluted with dry gas and its dew point measured to verify proper operation. Also, weighing of the amount of moisture adsorbed per unit time on a carbon dioxide pretreated Drierite column during the in-station tests confirmed the injection rates obtained by dew point flow rate measurements.

The delay time due to the length of the injection line for vapor injection was estimated to be of the order of seconds and therefore negligible.

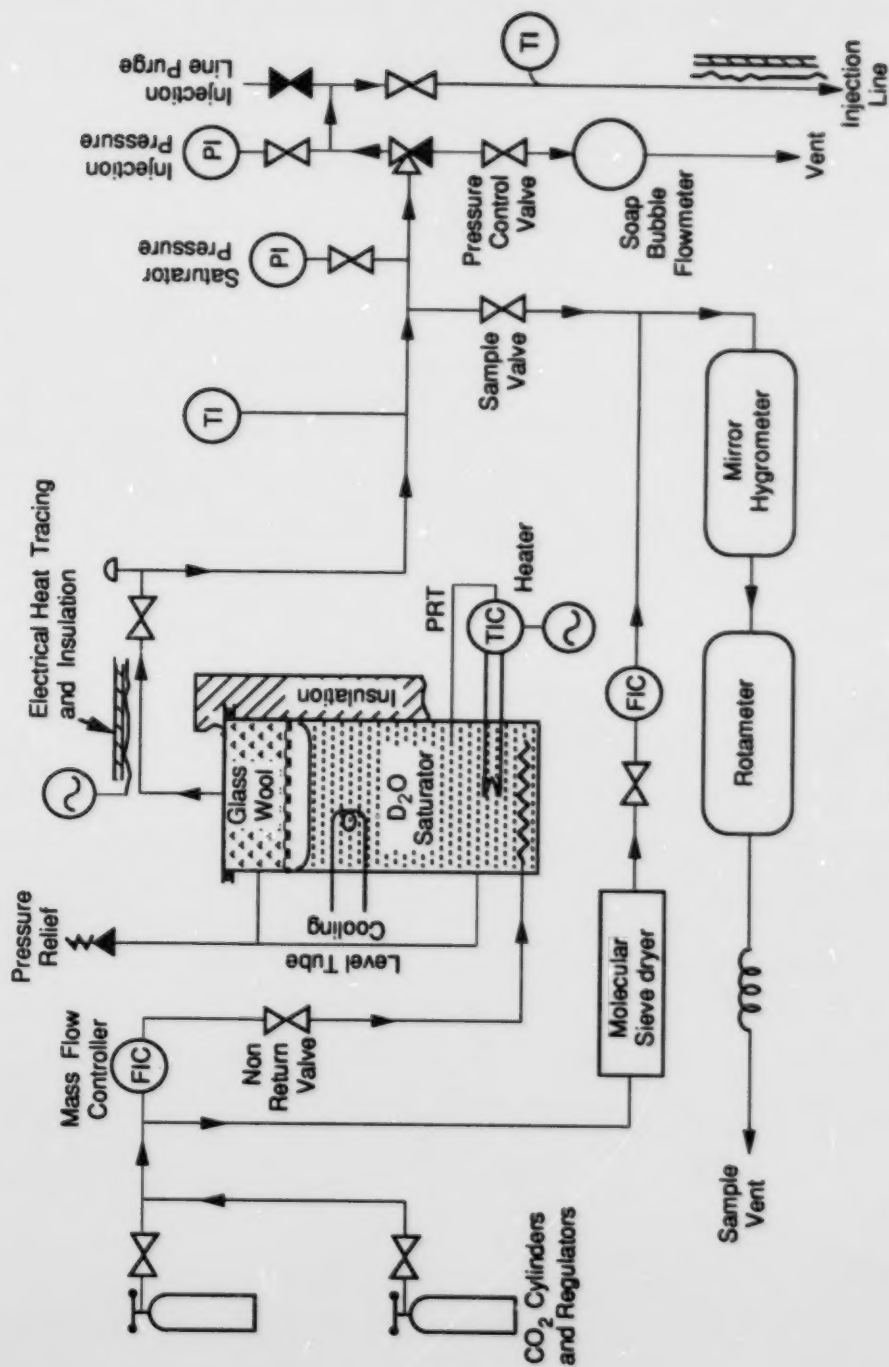


FIGURE 2
VAPOR INJECTION APPARATUS FOR TESTING
DEW POINT RESPONSE OF AGS

3.2 Sampling Equipment for Dew Point Measurements

The dew point measuring instrumentation and the measurement location are shown in Figure 3.

The two in-station Panametrics probes (J.Plourde, personal communication) and the Ontario Hydro Research Division (OHRD) sensors were calibrated for heavy water in carbon dioxide.

The Research Dew Point sampling train consisted of a Panametrics Aluminum Oxide sensor (68046PR), a MCM Silicon Chip sensor and an EG&G optical chilled mirror condensation type hygrometer. Readouts were obtained with a computer controlled data logging system. The sample stream flowed at about 1.7 L/min through the sensors. Because the various dew point meters were located close together, the pressures were similar making dew point corrections negligible.

3.3 Test Procedure

Prior to each moisture injection test, the annulus gas system was purged with bulk carbon dioxide until the dew point was usually less than -30°C . Following the purge, the AGS compressors were started up and an hour or more was allowed for stabilization of flow and pressure. During this period, the dew point increased in the system for whatever reason especially during the hot tests.

The D_2O vapor injection system was connected to the desired injection point, started up and placed on standby allowing saturation of the heavy water in the saturator with carbon dioxide. Various carbon dioxide flow rate checks and heavy water injection rate tests were carried out during this period.

The EG&G mirror dew point meter was usually cleaned and rebalanced before each test when the system was at its lowest dew point, i.e., the vapor in the AGS was predominantly light water. It tended to show an instability as the dew point rose to around -10°C d.p. and was occasionally rebalanced.

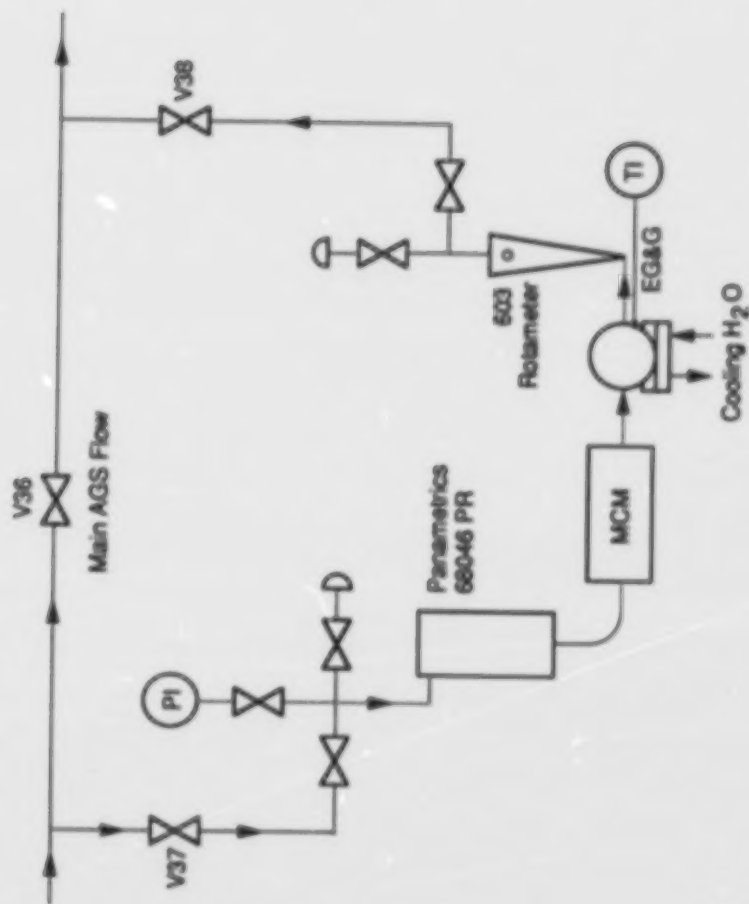


FIGURE 3
RESEARCH DIVISION D.P. SAMPLE TRAIN AT COLD
FINGER LOCATION

4.0 RESULTS AND DISCUSSION

Data on the temperature, pressure and flow rates in the AGS are given in Appendix C. As expected, the system pressure increased with time due to the carbon dioxide carrier gas injected with the water vapor. The total flow rate indication of the main flow rotameter (F150) was about 14% lower than the value found by calibration of a typical string rotameter and allowing for 48 strings. It appears (Appendix C) that about 30 to 40 kPa of pressure is being throttled between the compressor exit and the exit of the string rotameters. It is recommended that an investigation be carried out aimed at reducing this pressure loss to possibly increase the bellows life of the metal bellows compressor.

4.1 DEW POINT RESULTS

The dew point data for the five cold tests and the seven subsequent hot tests are given in Appendix A.

4.1.1 IN-STATION DEW POINT METERS

The test dates, test start times and in-station Panametrics dew point meter alarm times are given in Table 2. In general, the station dew point instruments read low by about 5 to 10 degrees for both hot and cold tests although they were calibrated with heavy water. Examination of the alarm times also showed significant differences between the field and control room readouts for the cold tests with better agreement for the hot tests.

4.1.2 OHRD DEW POINT METERS- HIGH DEW POINT PERFORMANCE

For a typical test shown in Figure 4, the readings of the OHRD instruments differ significantly at the beginning of the test but near the end of the test they converge with the Panametrics tending to read somewhat low. The reason for convergence at the end of the tests is that the MCM and Panametrics meters were calibrated to read dew points of a heavy water in carbon dioxide mixture and it was at the end of the tests that the injected heavy water vapor predominated over light water. Just after an AGS purge, light water predominated in the AGS since it was introduced with the purge gas. The dew point of the purge gas was -36°C at 92 kPa(g) when measured during test 15 at V50 (the planned oxygen addition point).

TABLE 2. TEST DATES, START AND ALARM TIMES

TEST NUMBER	DATE	TEST START TIME	TEST FINISH TIME	FIELD O.P. ALARM (-10C)	CONTROL ROOM O.P. ALARM (-10C)
1	MON 18 SEPT	18:30 18:30 18:30	23:00	MT51 22:58	MT51 21:07
5	TUE 19 SEPT	13:33	22:30	MT51 22:30	MT51 7
2	WED 20 SEPT	11:15	13:15	NO ALARM	NO ALARM
3	WED 20 SEPT	16:00	24:00	MT51 23:56	MT51 7
4	THURS 21 SEPT	11:00	20:20	MT51 20:09	MT51 7
6	THURS 23 NOV	11:00 11:00 11:00	13:14	MT51 13:03	MT51 7
8	FRI 24 NOV	13:21	17:25	MT51 17:21	MT51 17:06
9	SAT 25 NOV	11:00	18:06	MT51 18:06	MT51 17:40
10	SUN 26 NOV	11:10	16:24	MT51 16:23	MT51 16:05
13	MON 27 NOV	13:00	18:05	MT51 18:02	MT51 7
14	TUE 28 NOV	10:40	19:15	MT51 19:10	MT51 7
15	WED 29 NOV	13:20	16:00	NO ALARM	NO ALARM

DARLINGTON AGS TEST 1

Cold Tests

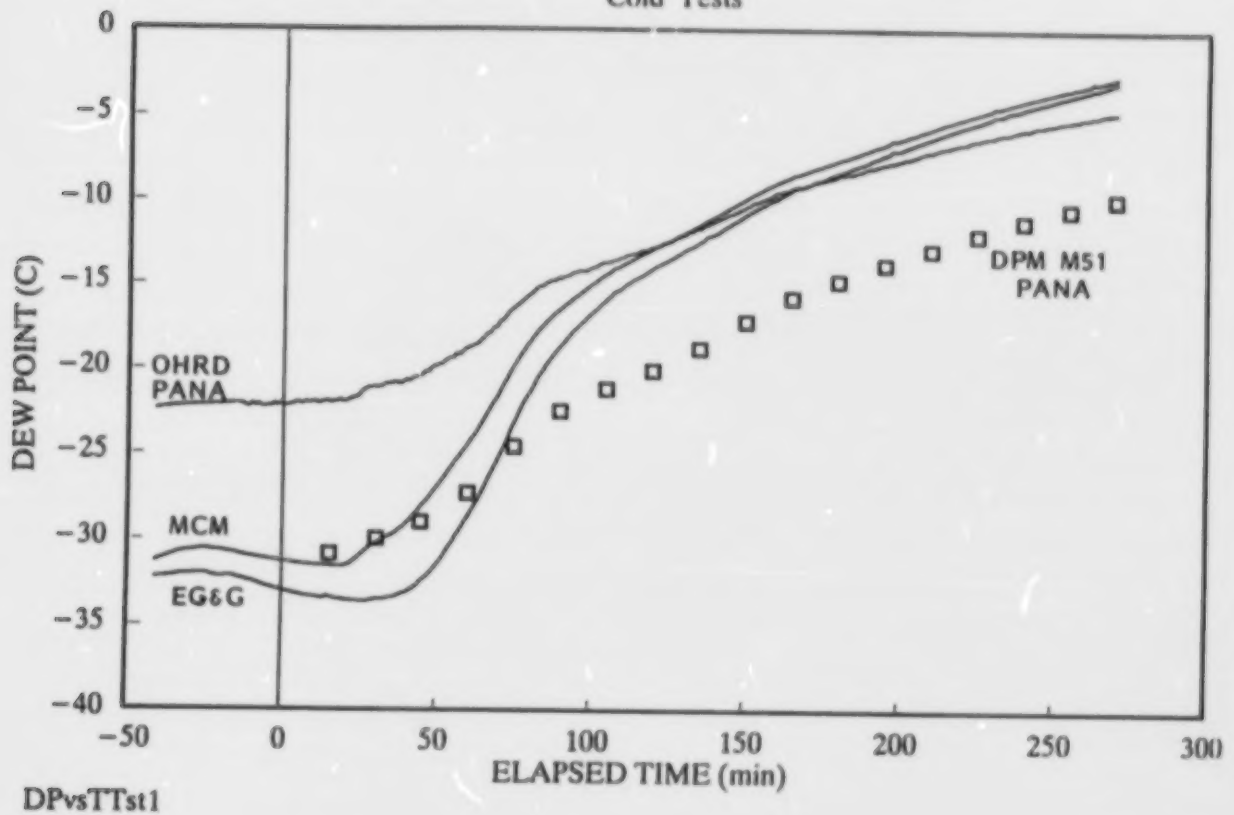


FIGURE 4
READINGS OF OHRD DEW POINT METERS CONVERGE AT HIGH DEW POINT

4.1.3 OHRD DEW POINT METERS- LOW DEW POINT PERFORMANCE

Assuming light water is the only isotopic species at the beginning of injection, it is possible to correct the readings of the Panametrics and MCM meters to obtain the starting dew point for use in a model developed by Nuclear Engineering Department. Graphs relating the true dew point to the reading of the Panametrics and MCM instruments depending on how they were calibrated and the isotopic species present in the vapor being measured are given in Appendix B. The results of the corrections are presented in Table 3 which shows that light water predominated at the start of injection during the cold tests but a mixture of light and heavy water was present at the start of four of the seven hot tests. Almost always for the hot tests, the system dew point rose continuously during the time interval between the end of the AGS purge and the start of injection as a result of slow system desorption, insufficient purge time (although on two occasions the AGS was purged continuously for 15 hours each time), dead areas in the AGS or other effects. Moreover, as discussed below, it appeared that the species being desorbed, etc. was heavy water rather than light water. Hence, at the start of injection for these tests, the AGS consisted of a mixture of light and heavy water as discussed below. This gradual increase in dew point between the end of AGS purging and the start of injection was not seen during the cold tests.

In the case of the EG&G condensation hygrometer, the accuracy of the values depended on whether sufficient time was allowed for stabilization at low dew point where frost layer build up was usually slow and if the species on the mirror was the same as that in the gas. Just after an AGS purge, the species present on both the mirror after rebalance and in the gas was light water and hence given enough time with no heavy water desorption from the AGS system, the dew point values were correct before injection. Near the end of the injection test, the light water frost on the mirror was completely replaced by heavy water frost; since at this time heavy water predominated in the system, the readings were also correct at high dew point. During the intermediate period with both light and heavy water on the mirror and in the gas, the maximum error due to this effect was a 3.5°C low reading. This corresponded to light water only on the mirror and heavy water only in the gas.

TABLE 3 DEW POINT AT START OF TESTS

TEST NUMBER	DEW POINT AT START OF TEST TC22	DEW POINT AT START OF TEST PARA	DEW POINT AT START OF TEST NON CORR	DEW POINT AT START OF TEST NON RAW	SPECIES PRESENT IN GAS	SPECIES * PRESENT ON MIRROR	NOTES RELEVANT
1	-33.8	-32.2		-32.3	R20	R20	
2***	-37.8	-32.9		-33.0	R20	R20	N2O BUT PARA READS HIGH
3	-32.7	-32.9		-33.2	R20	R20	SAME AS ABOVE
4	-37.2	-33.5		-33.3	R20	R20	SAME AS ABOVE
5	-32.5	-32.4		-32.7	R20	R20	SAME AS ABOVE
6	-22.8	-22.2		-22.7	R20	R20	N2O
8	-28.8	-27.2	-27.8	-27.9	R20	R20	N2O/D2O MIXTURE
9	-28.8	-27.2	-27.2	-28.2	R20	R20	N2O
10	-28.2	-27.9	-27.2	-28.7	R20	R20	N2O/D2O MIXTURE
13	-27.8	-23.1	-23.8	-27.7	R20	R20	N2O/D2O MIXTURE
14	-27.8	-23.8	-23.3	-27.3	R20	R20	N2O
15****	-33.8	-33.3	-33.3	-32.2	R20	R20	N2O

* RELEVANT TO EGGS ONLY

** ALSO COMPARISON OF TIME GRAPHS, APPENDIX D

*** THIS IS A COLD PLUG TEST; ASSUMING N2O ONLY PRESENT, NON AGREES WITH EGGS, BUT PARA READS 2 DEG HIGH

**** THIS IS A HOT PLUG TEST; ASSUMING N2O ONLY PRESENT, NON CORRECTED AGREES WITH EGGS AND PARA

4.2 CONCENTRATION RESULTS

The outputs of the Panametrics and EG&G meters depend on both the pressure of the water vapour and on whether the species present in the surrounding gas (and on the mirror) is light or heavy water. However, the output of the MCM instrument depends on vapor pressure only and comparison of these readings from the MCM with the Panametrics and EG&G allows additional information on the behaviour of water in the AGS.

The dew point data of the cold and hot tests are replotted in terms of concentration in Appendix D. The readings of the Panametrics and the MCM meters were converted to true dew point assuming either light water or heavy water was present in the gas, then the vapor pressure at the true dew point was calculated for the particular isotope assumed present from the $\ln p$ vs $1/T$ relationship and the concentration was obtained by dividing the vapor pressure by the total system pressure at the dew point meters. For the EG&G meter, the procedure was similar except that the assumption was that the species on the mirror was light or heavy water.

4.2.1 DEW POINT/CONCENTRATION SENSITIVITY AND RELATIONSHIP

Figure 5 shows the dew point and concentration curves for test 13 as a function of time. Examination of the concentration graph and those presented in Appendix D shows that after the initial period of step changes in concentration, the concentration increased linearly with time showing a constant rate of moisture addition. Hence, any increase in leak rate is easily detected visually by a sudden increase in slope of a concentration versus time graph. However, during the initial period of the leak, Figure 5 shows that the more sensitive parameter is dew point because of the larger height of the initial increase at the 50 minute mark.

The relationship between dew point and concentration is illustrated in Figure 6 in which dew point is plotted against time together with inverse dew point and the natural logarithm of the concentration for the MCM meter (all normalized). It is seen that the log concentration versus time curve may be thought of as the same approximately as the dew point vs time curve (both normalized); however, based on the $\ln$ pressure versus $1/T$ relationship, it is the log concentration and inverse dew point versus time curves which are identical.

For display purposes, therefore, plotting dew point or log concentration vs time allows sensitivity at "leak" commencement and plotting concentration vs time curves indicates whether the "leak" is increasing with time.

4.2.2 ISOTOPIC SPECIES PRESENT FROM CONCENTRATION DATA

Figure 7 shows that the initially light water filled AGS became predominantly heavy water filled as injection was continued. Furthermore, the concentration of the total water species was given by one line for the MCM instrument over the entire period of the test while concentration values were only correct for the EG&G instrument at low dew points (where light water predominated) and at high dew point (where heavy water predominated).

DARLINGTON AGS TEST 13

MCM Corrected

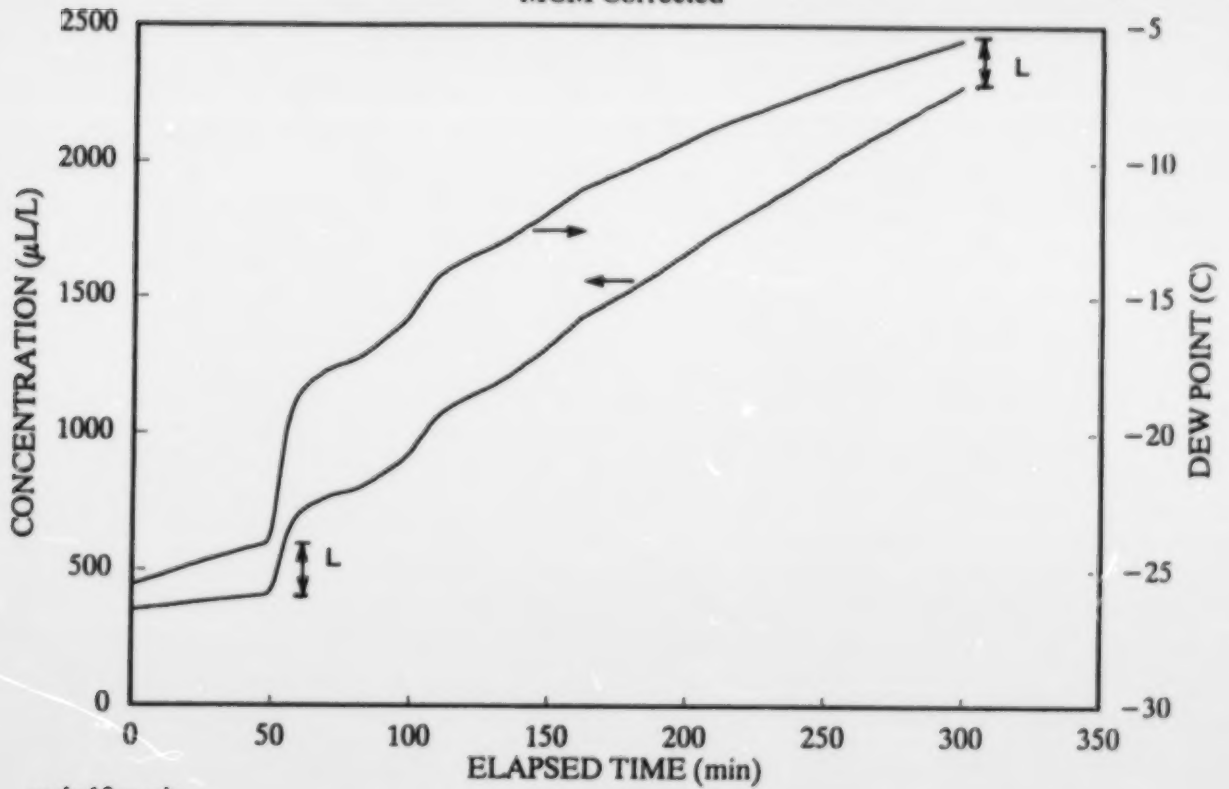


FIGURE 5

DEW POINT IS A MORE SENSITIVE PARAMETER AT THE START OF A "LEAK"

DARLINGTON AGS TEST 13

MCM Corrected

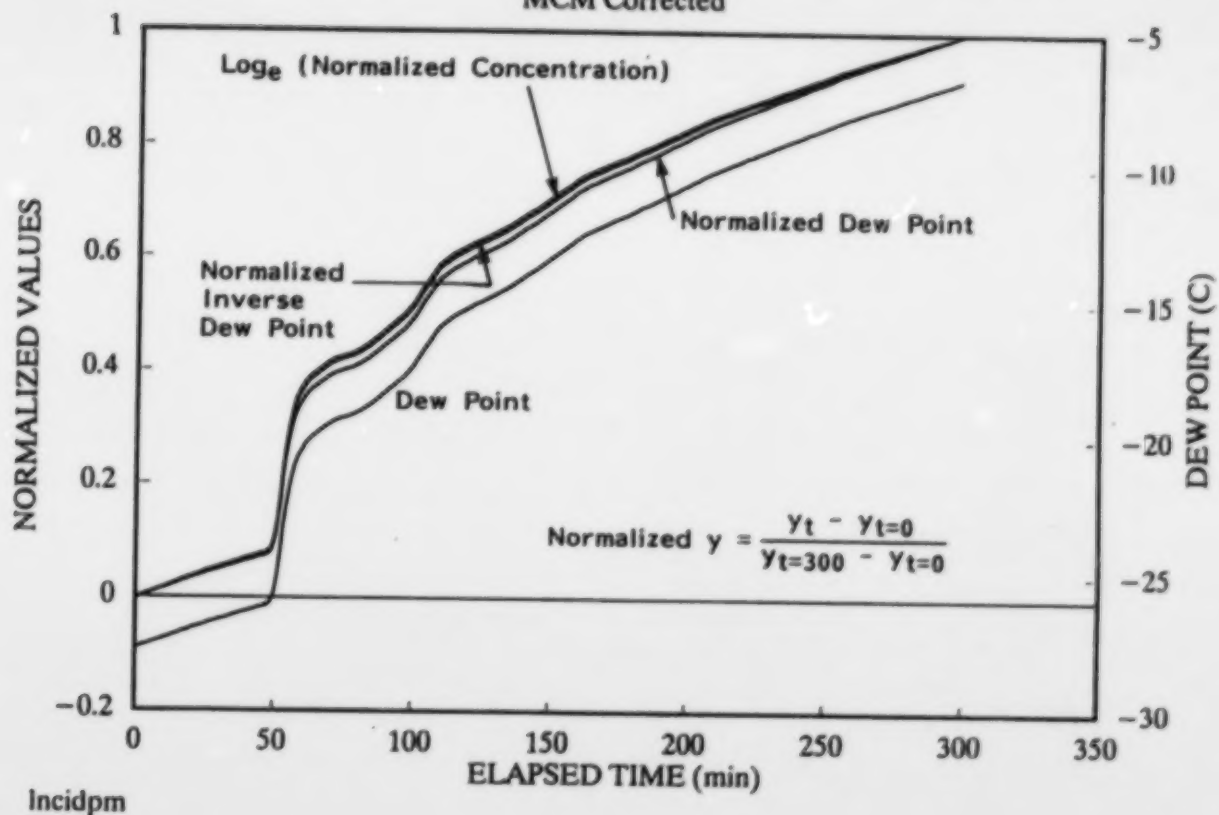


FIGURE 6

APPROXIMATE SIMILARITY OF LOG CONCENTRATION
AND DEW POINT CURVES (BOTH NORMALIZED)

DARLINGTON AGS TEST 9

MCM CORRECTED

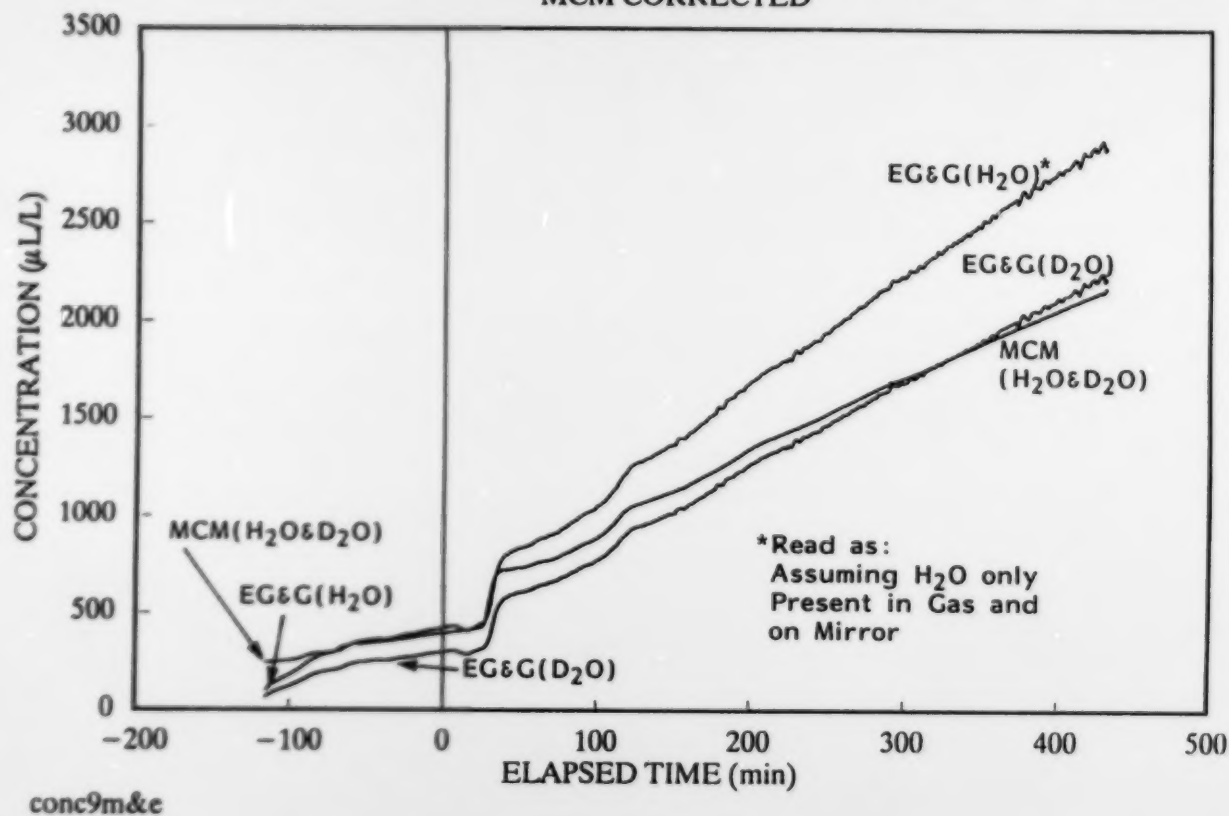


FIGURE 7

MCM METER SHOWS THE CONCENTRATION INCREASE IS INDEPENDENT OF THE ISOTOPIC FORM PRESENT IN THE AGS

The OHRD Panametrics meter behaved similarly to the EG&G. It tended to read slightly higher at low concentration and slightly lower at high concentration during the cold and hot tests. A peculiarity of the Panametrics behaviour is shown in Figure 8 for the initial period of test 8 in which the MCM (and EG&G, see Appendix D) showed an increasing concentration of water in the AGS but the Panametrics showed no change in water concentration. This is believed due to the slow dry down behaviour of the Panametrics which gives a falling output and its reduced output signal with D₂O being counteracted by the slowly increasing system dew point.

Figure 8 and the EG&G response for test 8 show that light water and some heavy water vapor were present at the start of this test.

Figure 9 shows that the species present at the beginning of the constant purge hot reactor test (15) was light water but the vented gas at the end of the test was a mixture of light and heavy water. The MCM response was significantly faster to steady state than the EG&G response. A similar result was obtained for cold reactor conditions.

4.2.3 METHOD FOR DETERMINING LEAKING SPECIES

The above data point to the possibility of using an MCM in series with a Panametrics hygrometer (or EG&G meter if the response is sufficiently rapid) for determining the isotopic concentration in the AGS gas and therefore identifying if a leak is a light or heavy water one. It may be of advantage for early indication at low dew points where a significant time may be required to collect a sufficient sample by the presently employed cold finger condensation method. The test can be carried out by installing the meters temporarily at the cold finger location. It will be necessary to provide accurately and recently calibrated instruments to be able to detect the small differences expected in the readings. Carrying out this test under constant purge conditions appears promising since the differences are slightly larger at low concentrations and a steady state concentration level is expected.

4.2.4 CONCENTRATION RESULTS - INITIAL BACKGROUND INCREASE

The rate of rise of concentration before injection was commenced was only noticeable in the hot tests. These data are summarized in Table 4.

Table 4 shows that the rate was remarkably constant over the hot test period even though two very long purge times were employed before each of tests 9 and 10. Field data have shown /D.Beaton(personal communication)/ that the reactor takes several weeks to dry out fully suggesting that adsorption does occur. A rate of rise of 1 $\mu\text{L/L/min}$ in an AGS volume of 15000L corresponds to a water addition rate of about 0.8g/h which is significant compared to some of the injection rates used during single compressor operation(Table 1).

DARLINGTON AGS TEST 8

MCM CORRECTED

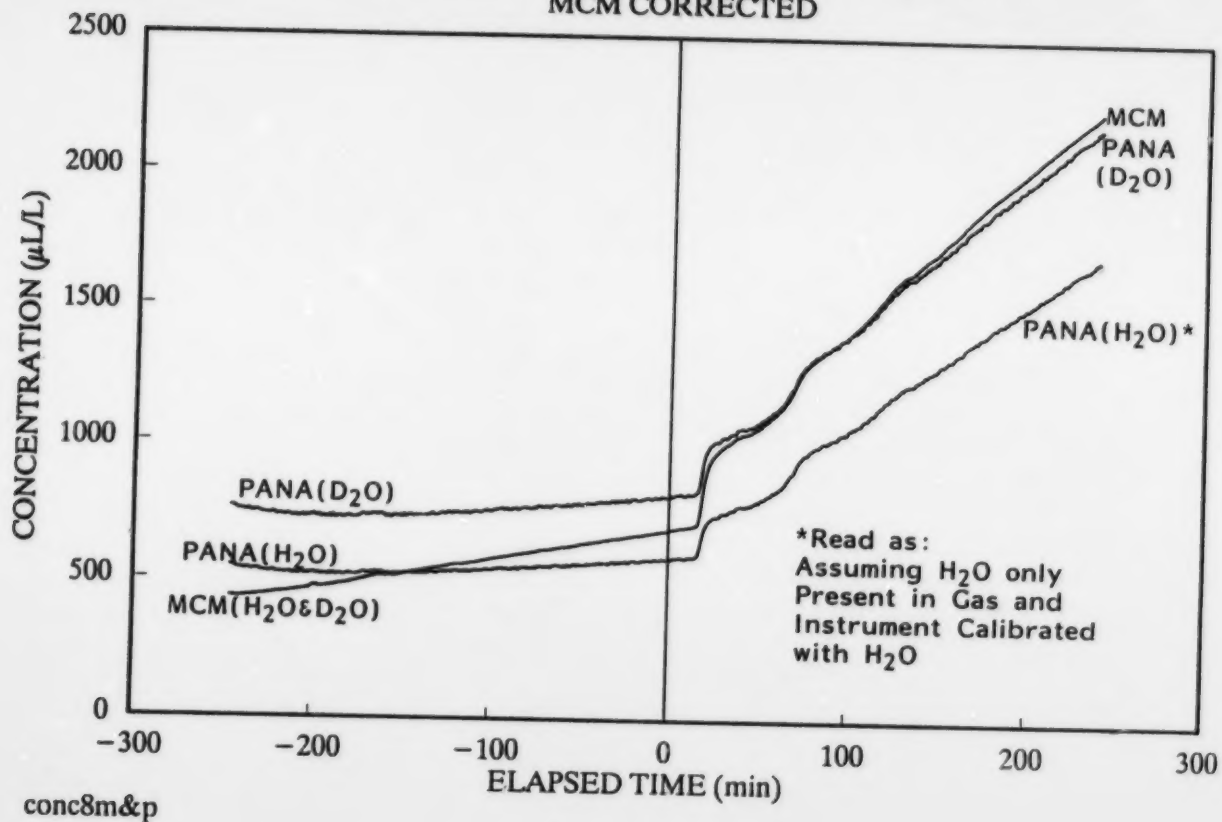


FIGURE 8
CONSTANT PANAMETRICS READINGS WITH INCREASING
 D_2O CONCENTRATION AT LOW CONCENTRATION

DARLINGTON AGS TEST 15

MCM Corrected

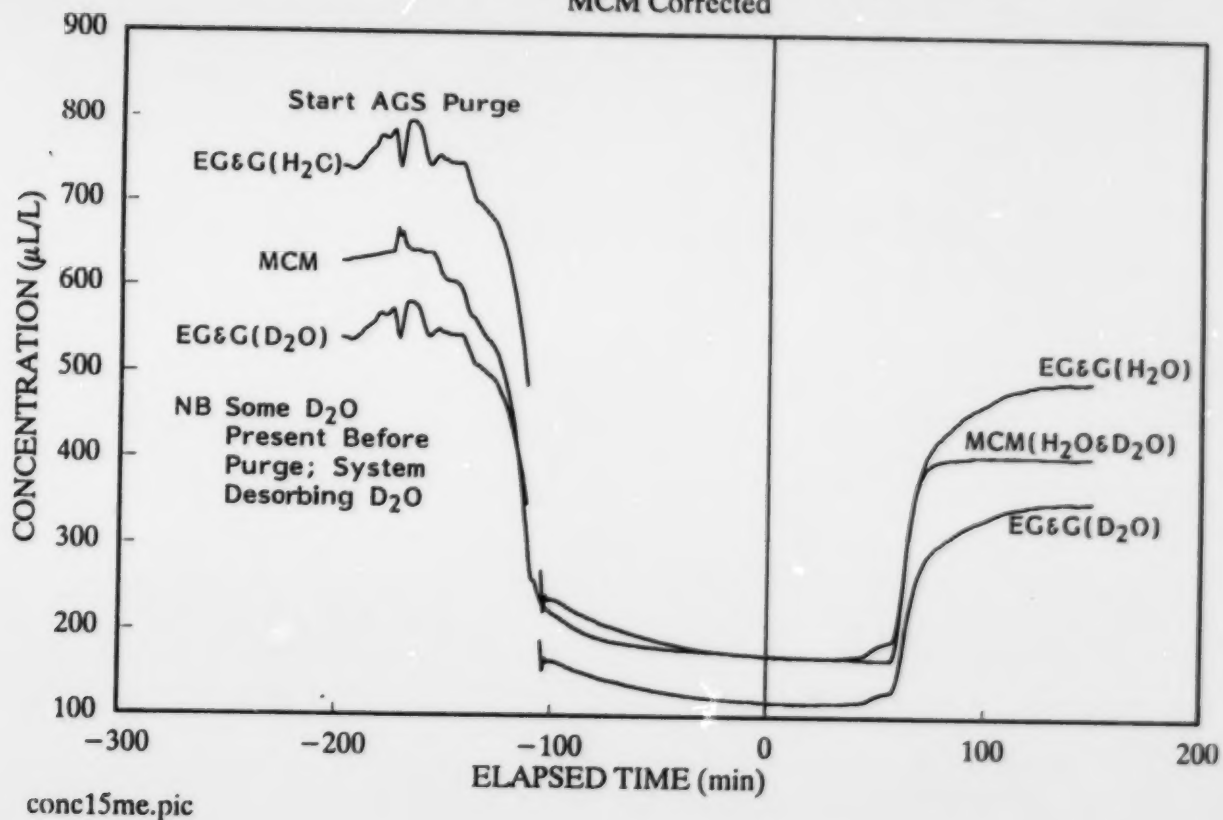


FIGURE 9
FOR A 3.4 g/h "LEAK", THE EXITING PURGE GAS IS A MIXTURE OF LIGHT AND HEAVY WATER

Table 4. Rate of Rise of Concentration Before Injection During Hot Tests

Test Number	Test Date	Purge Duration Before Test (hours)	Rate of Rise $\mu\text{L/L/min}$
6	Thurs 23 Nov	?	1.07
8	Fri 24 Nov	?	1.12
9	Sat 25 Nov	21	1.15
10	Sun 26 Nov	21	1.10
13	Mon 27 Nov	4.5(total)	1.13
14	Tue 28 Nov	~ 4(estimated)	1.11

4.2.5 CONCENTRATION RESULTS - CORRECTION FOR INITIAL BACKGROUND INCREASE AND PRESSURE INCREASE DUE TO ADDED CARBON DIOXIDE

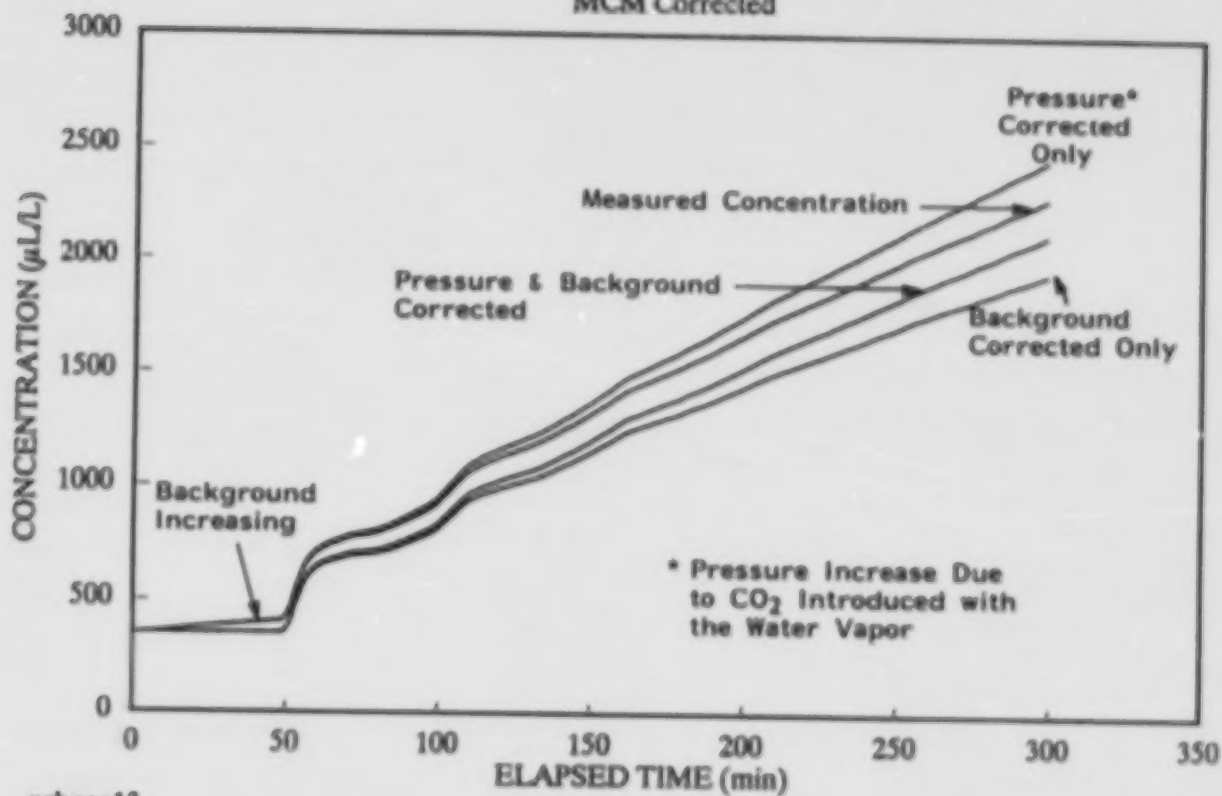
Unlike concentration data, it is more difficult to correct dew point vs time data for a background dew point rise rate before the start of injection. Figure 10 shows:

- (i) the measured concentration as a function of elapsed time,
- (ii) the concentration/time relationship if the initial concentration rise rate is removed (the data of Table 4 show that it probably remains constant over the test period),
- (iii) the concentration/time relationship if the pressure rise due to the carbon dioxide injected is allowed for, and
- (iv) the predicted concentration/time relationship corresponding to the injection rate of 4.5g/hr used in test 13.

Such corrections are necessary in developing models for the AGS performance.

DARLINGTON AGS TEST 13

MCM Corrected



prbgco13

FIGURE 10
PREDICTED CONCENTRATION/TIME RELATIONSHIP AFTER
CORRECTION FOR PRESSURE AND BACKGROUND INCREASES

4.2.6 Effect of String Length

The effect of string length is shown in Figures 11 and 12 for a cold and hot reactor, respectively. The time to first response which depends on the string volume and the flow rate under the prevailing pressure and temperature conditions increased with the length of the string as expected.

For the cold tests (Figure 11), the slopes of the concentration/time curves at high concentrations were similar but the slope of the 11 channel string curve was slightly smaller due to the smaller injection rate. For the hot tests (Figure 12) and also at high concentrations, the slope of the response curves for the 4 and 11 channel strings were also similar but the slope of the 12 channel string curve was significantly larger although the injection rates were identical. Also, the magnitude of the initial increase was larger for this test. The result suggests a moisture addition rate in excess of 4.5 g/h but we cannot explain this at present.

For the cold tests (Figure 11), it is readily seen that the initial slope was much sharper for the 4 channel string as compared to the 11 and 12 channel strings probably as a result of increased opportunity for back mixing in the longer strings and a larger effect of any adsorption process. As shown in Figure 12, the effect was not as pronounced for the hot tests. The significance of the initial and "steady state" slopes on the location of a leak will be discussed below.

4.2.7 Effect of Cold vs Hot Reactor

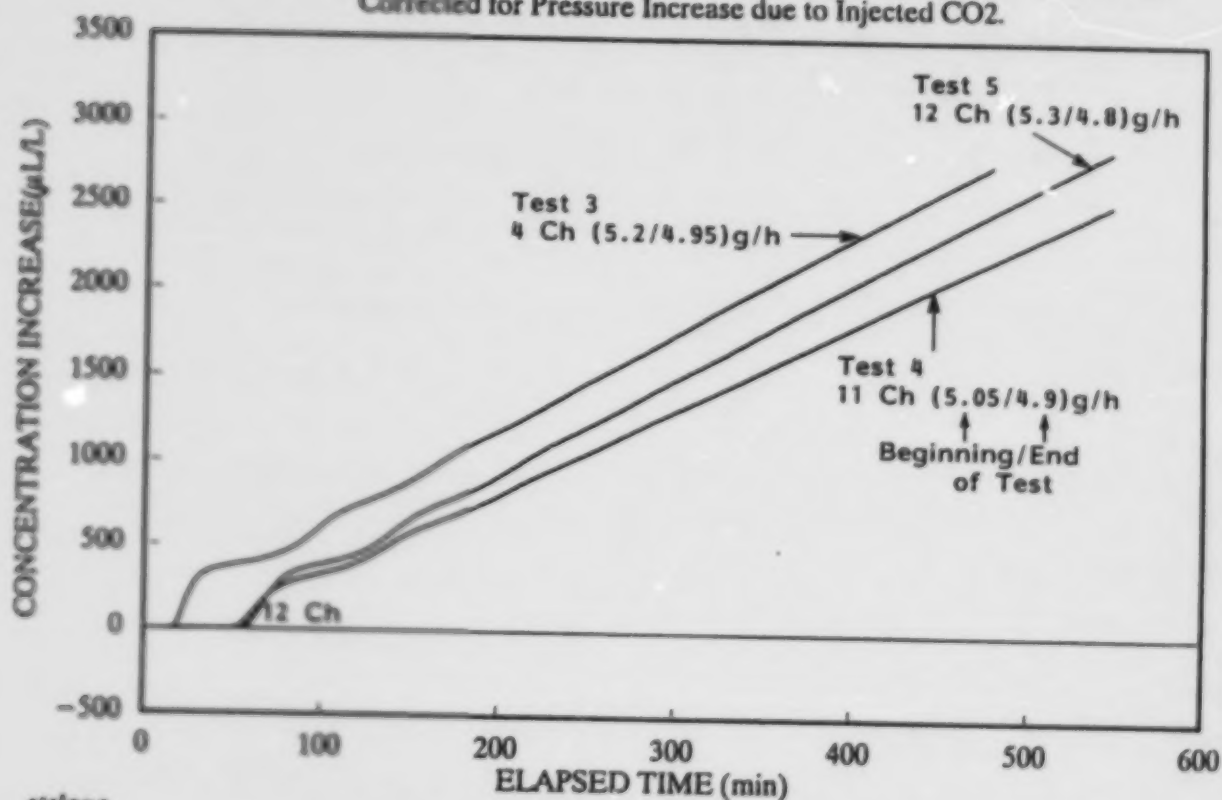
The effect of reactor temperature for a long string of 11 channels, a short string of 4 channels and for external injection to the overall circuit is shown in Figures 13, 14 and 15.

Figure 13 shows that the water travelled through the string faster in the hot reactor even though the NTP string flow rate was about 7% slower after correcting for different pressures during the cold reactor test. The lower residence time for the hot reactor was probably due to the higher velocity of the expanded gas due to the temperature increase and possibly adsorption in a cold reactor. Also, the initial slope for the concentration vs time curve was greater for the hot reactor and higher levels of moisture were achieved in the recirculating gas of the hot reactor even though the injection rate was about 10% less for the hot tests. It is recommended that helium be injected together with water vapor in future tests to investigate the importance of adsorption effects.

Figure 14 shows that the delay time was reduced with a shorter string as was the additional delay due to the cold reactor; however, the difference in the initial slopes with injection into the cold and then hot reactor was not as clear for this shorter four string channel.

DARLINGTON AGS TESTS 3, 4 AND 5

Corrected for Pressure Increase due to Injected CO₂.



string

Channels in String	String Flow Rate (L/min NTP/at Pressure)	String Pressure Inlet/Outlet kPa(g)
4	7.5/5.77	38/24
11	7.7/5.47	51/31
12	7.55/5.64	44/25

FIGURE 11
EFFECT OF STRING LENGTH FOR COLD REACTOR AT 15%
ABOVE NORMAL TEST STRING FLOW RATE

DARLINGTON AGS TESTS 8, 10 and 13

Corrected for Pressure and Background Increase

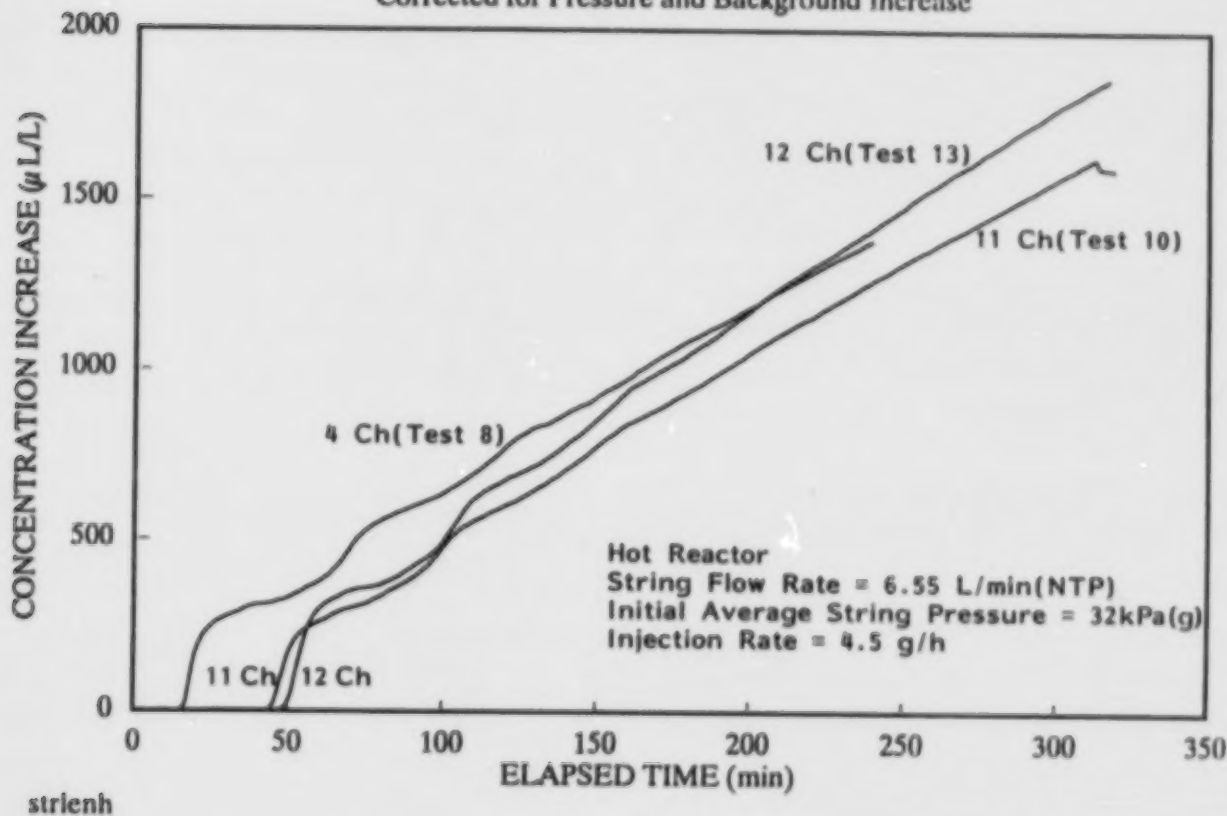
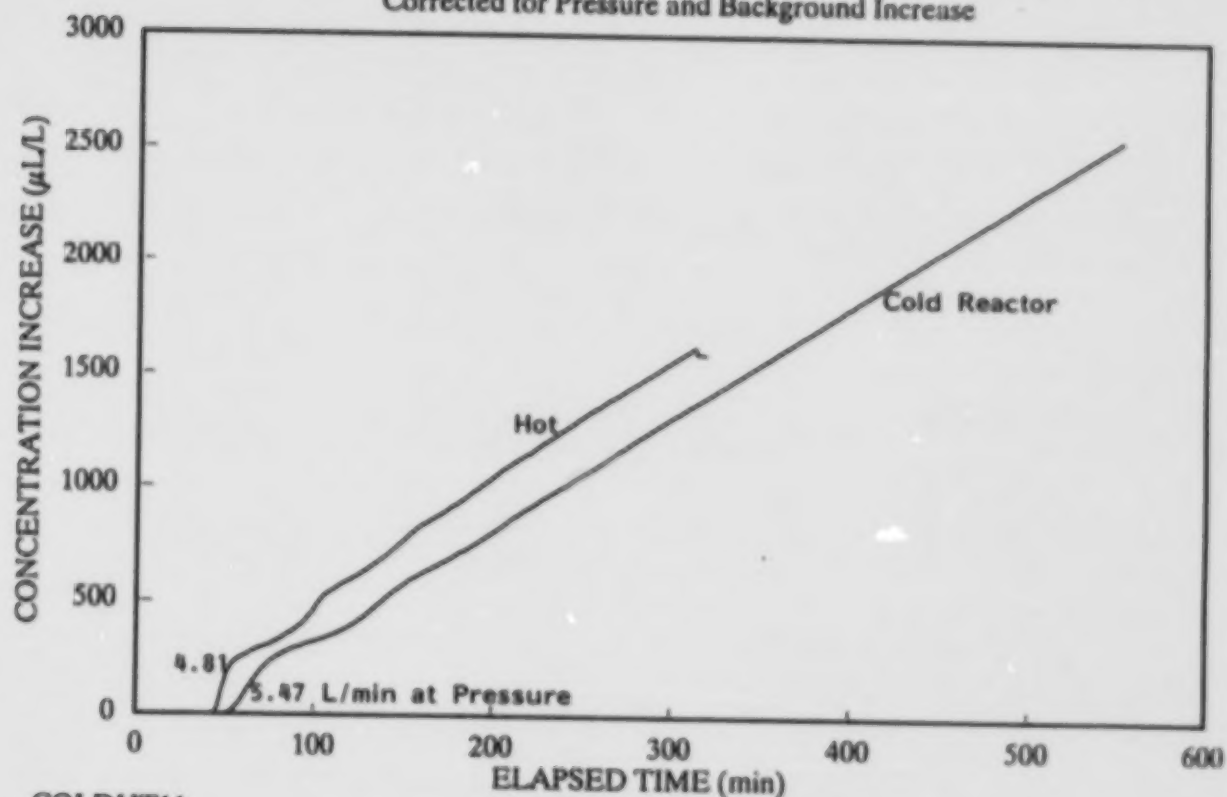


FIGURE 12
EFFECT OF STRING LENGTH FOR HOT REACTOR
AT NORMAL STRING FLOW RATES

DARLINGTON AGS TESTS 4 and 10

Corrected for Pressure and Background Increase



COLDHT11

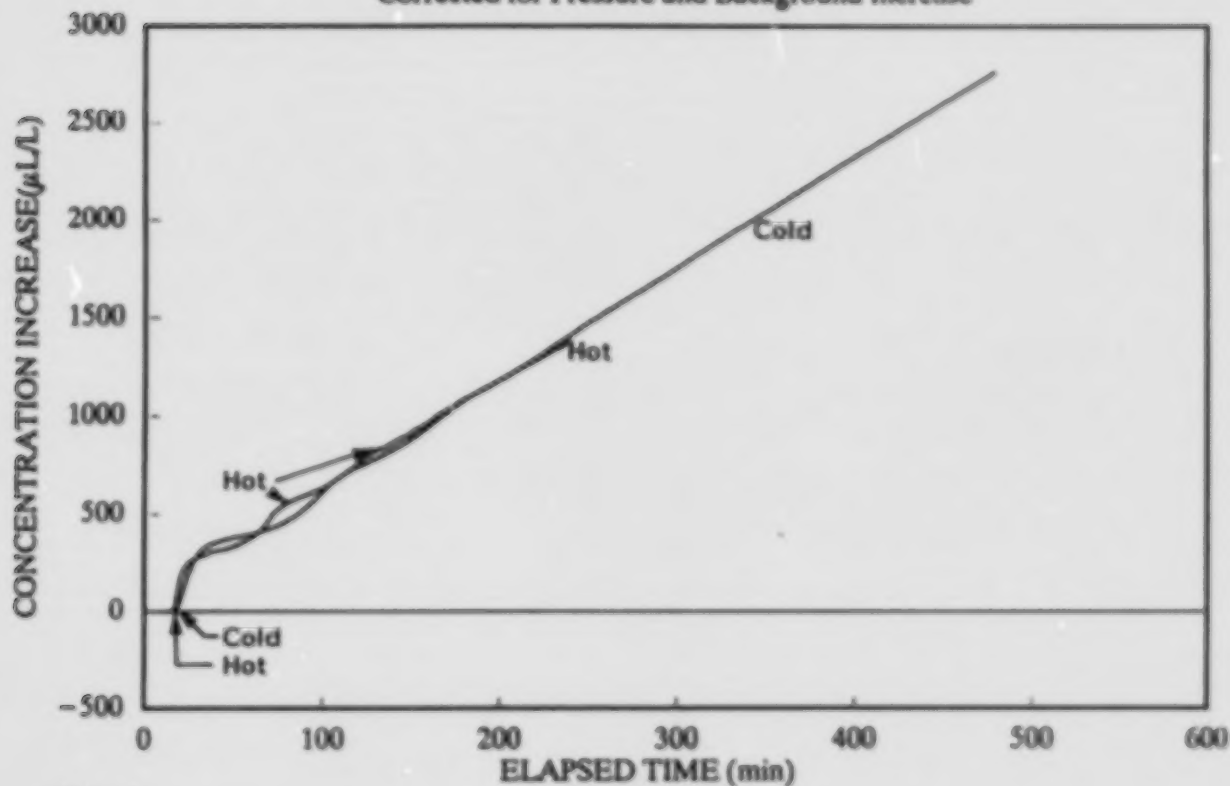
11 Channel String	Cold	Hot
Injection Rate	5.05/4.9	4.5 g/h
String Flow Rate	7.5	6.55 L/min (NTP)
String Inlet/Outlet Pressure	51/31	46/27 kPa(g)
String Flow Rate	5.47	4.81 L/min (at Pressure)

FIGURE 13

THE INITIAL SLOPE IS GREATER FOR A HOT REACTOR
ESPECIALLY FOR LONG STRINGS AND THE
INITIAL SIGNAL APPEARS EARLIER

DARLINGTON AGS TESTS 3 and 8

Corrected for Pressure and Background Increase



coldhot4

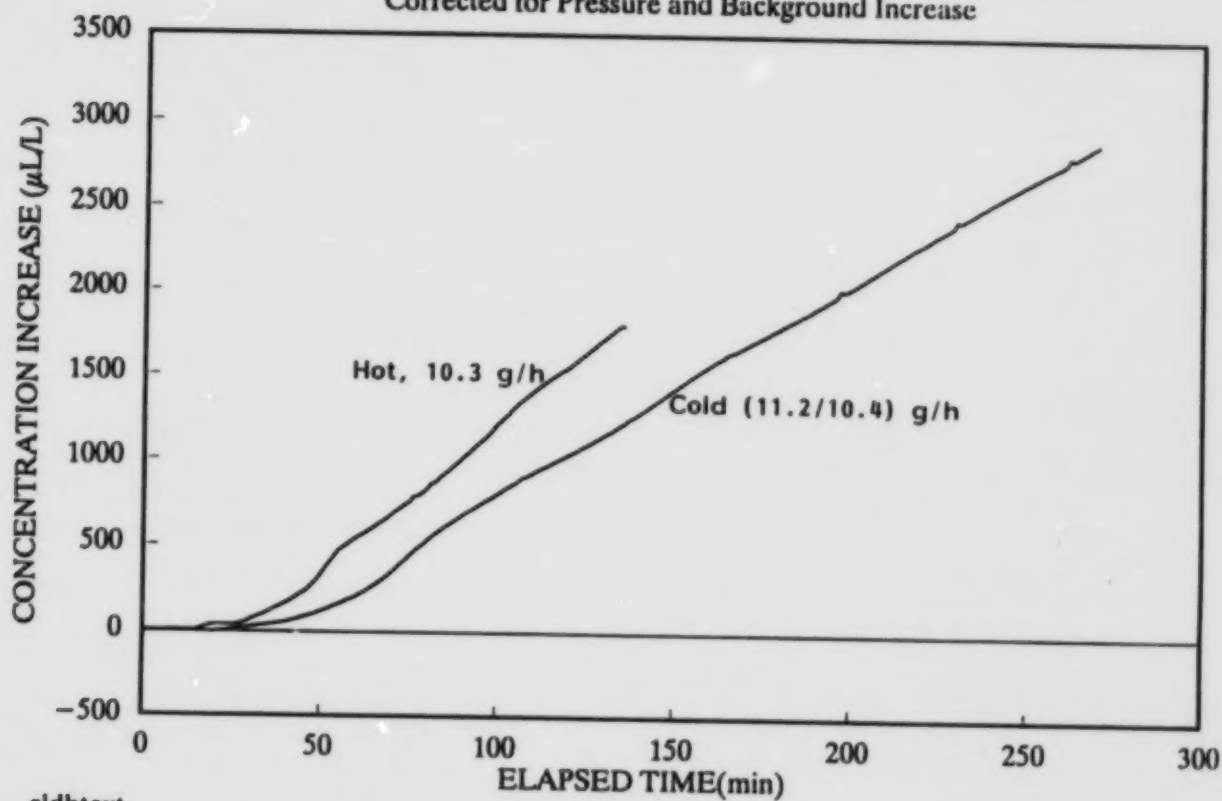
4 Channel String	Cold	Hot
Injection Rate	5.2/4.95	4.5 g/h
String Flow Rate	7.5	6.55 L/min (NTP)
String Inlet/Outlet Pressure	36/24	36/26 kPa(g)

FIGURE 14

THE INITIAL RESPONSE IS FASTER FOR A HOT REACTOR EVEN AT 15% LOWER TEST STRING FLOW RATES

DARLINGTON AGS TESTS 1 and 6

Corrected for Pressure and Background Increase



cldhtext

FIGURE 15
WITH EXTERNAL INJECTION, THE INITIAL SHARP PEAK IS SUPPRESSED

Figure 15 shows that with external injection into the main flow, the initial sharp peak was suppressed because the injected moisture was divided into 48 strings. The water concentration increased more rapidly in the hot recirculating gas suggesting adsorption in the cold reactor and/or a moisture addition rate higher than 10.3g/h during the hot test. This could have been due to splashing of heavy water to the saturator outlet tube during movement from storage to the injection area.

4.2.8 Effect of Internal versus External Injection

The response of the AGS to internal and external injections into a hot reactor is shown in Figure 16 and the response for a cold reactor is shown in Figure 17. As expected, both figures show that the initial signal for the external circuit injection occurred at the same time as the initial signal for the four channel string. The initial signal strength was much less for the external injection case because the 10g/h injection rate was divided into 48 strings.

Figures 16 and 17 also show that the "steady state" rate of rise of concentration increased with injection rate. A simple plug flow model presented in Appendix F shows that the rate of concentration rise is proportional to the injection rate. In the case of the hot reactor(Fig 16), a 125% increase in injection rate resulted in a 225% increase in the rate of concentration rise. Similarly, in the case of the cold reactor(Fig 17), the rate of rise was approximately proportional to the injection rate with a 100% increase in the injection rate resulting in a 125% increase in the rate of rise of concentration.

The response curve for the 5g/h injection into the four channel string and that for a similar injection into a twelve channel string were summed and compared to the response curve for the 10g/h injection into the external circuit. The results are presented in Figures 18 and 19 for a cold reactor and a hot reactor, respectively. The figures show acceptable agreement between the external injection and the summed internal injections after the first hour of injection but as observed before, the rate of rise of concentration for the hot reactor was on the high side.

4.2.9 Effect of Single Pass Purge Mode Operation

The response curve for purge mode operation (Tests 2 and 15) approximated a step increase in the outlet concentration to a steady state value determined by the overall flow rate and the moisture addition rate. Figure 20 shows that the final steady state concentration increase was measured at 320 $\mu\text{L/L}$. This is similar to 360 $\mu\text{L/L}$ calculated from the injection rate of 4.8 g/h D_2O (0.0978 L/min NTP) and the overall flow rate of 276 L/min(NTP) given by FI50. Assuming an overall flow rate of 14% greater as suggested by the calibration of a string rotameter shows better agreement with a concentration rise of 310 $\mu\text{L/L}$. For the hot reactor

DARLINGTON AGS TESTS 6 and 8

Corrected for Pressure and Background Increase

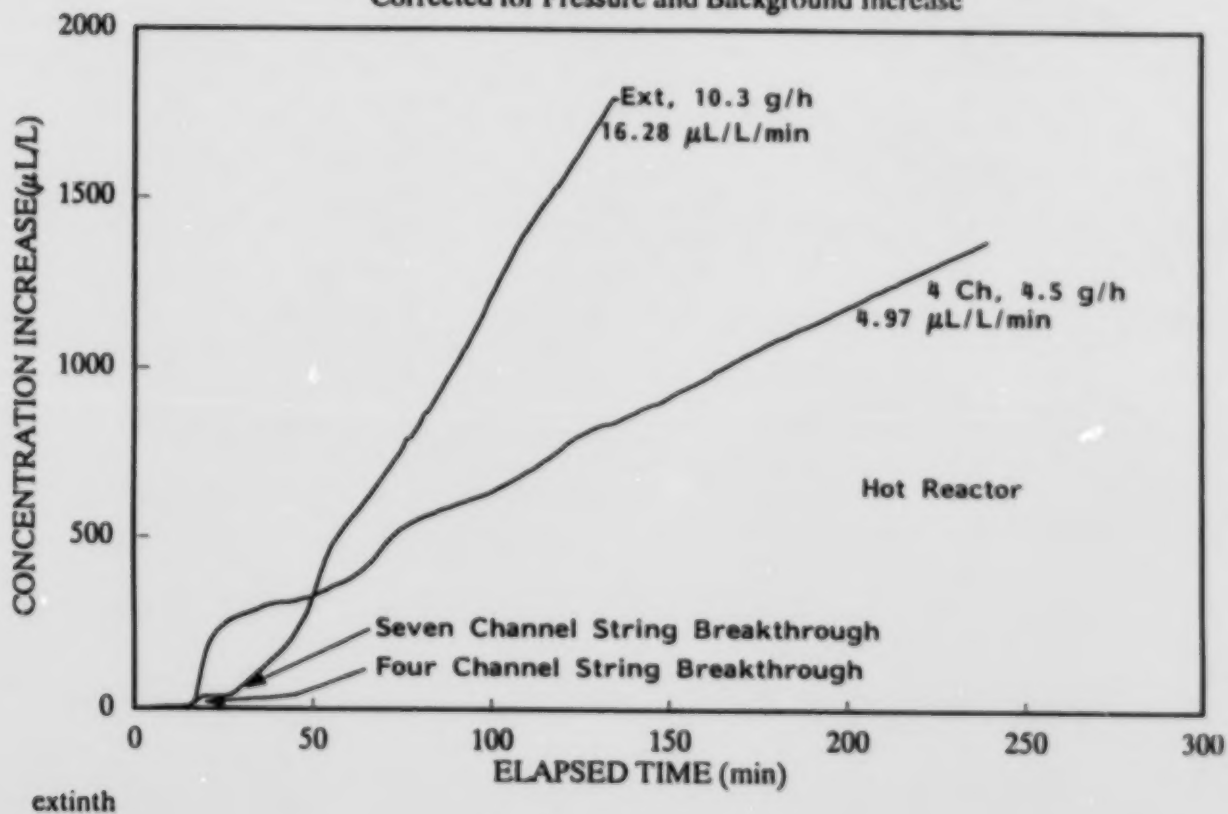


FIGURE 16

THE INITIAL SIGNAL FOR EXTERNAL INJECTION COINCIDES WITH THAT FOR FOUR CHANNEL STRING INJECTION

DARLINGTON AGS TESTS 1 AND 3

Corrected for Pressure and Background Increase

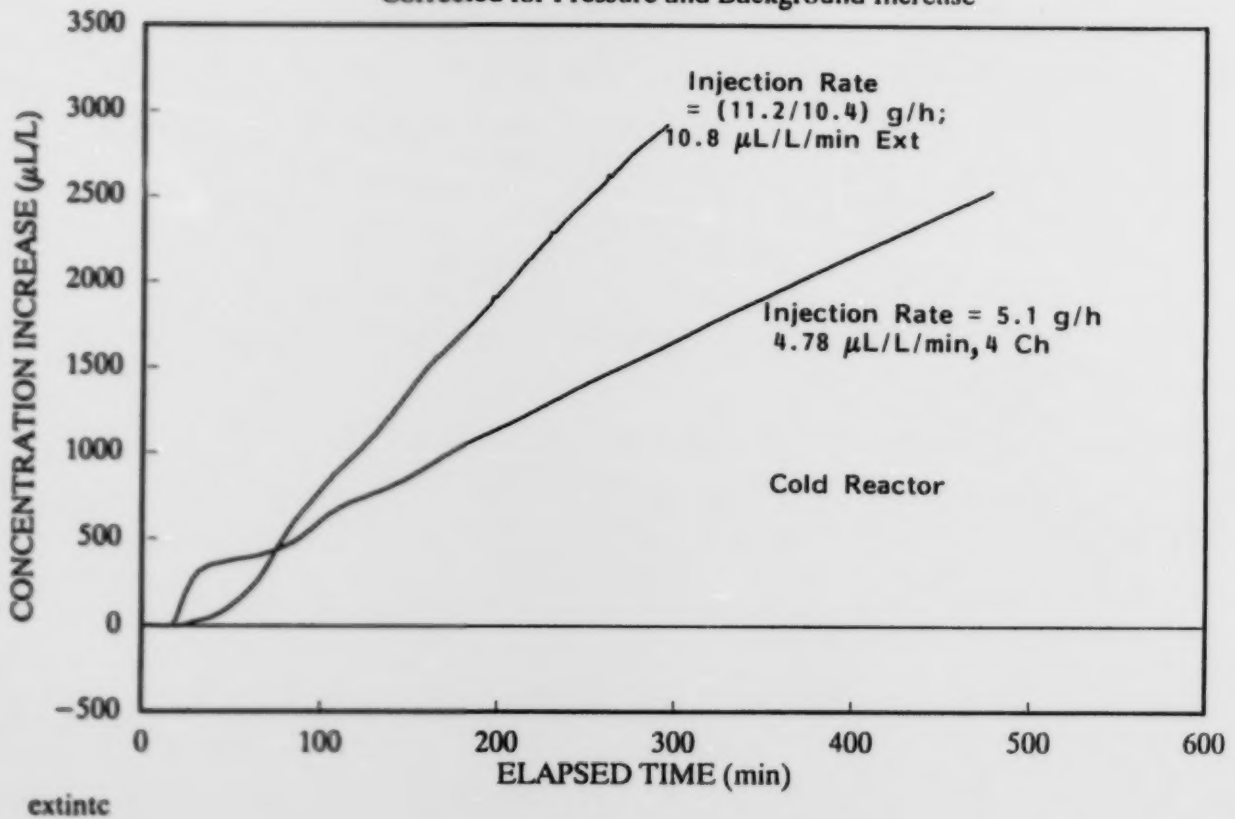
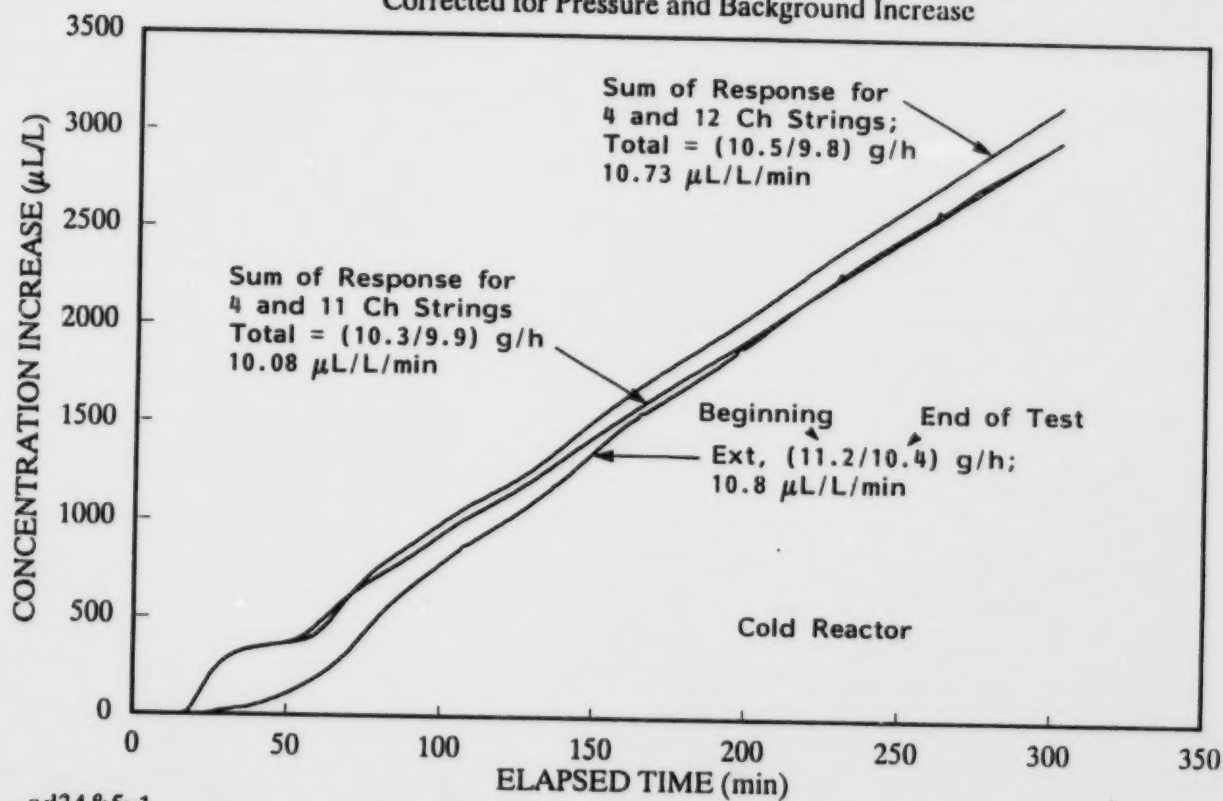


FIGURE 17

THE RATE OF INCREASE IN CONCENTRATION AT "STEADY STATE"
WAS APPROXIMATELY PROPORTIONAL TO THE INJECTION RATE

DARLINGTON AGS TESTS 1 AND 3+4, 3+5

Corrected for Pressure and Background Increase



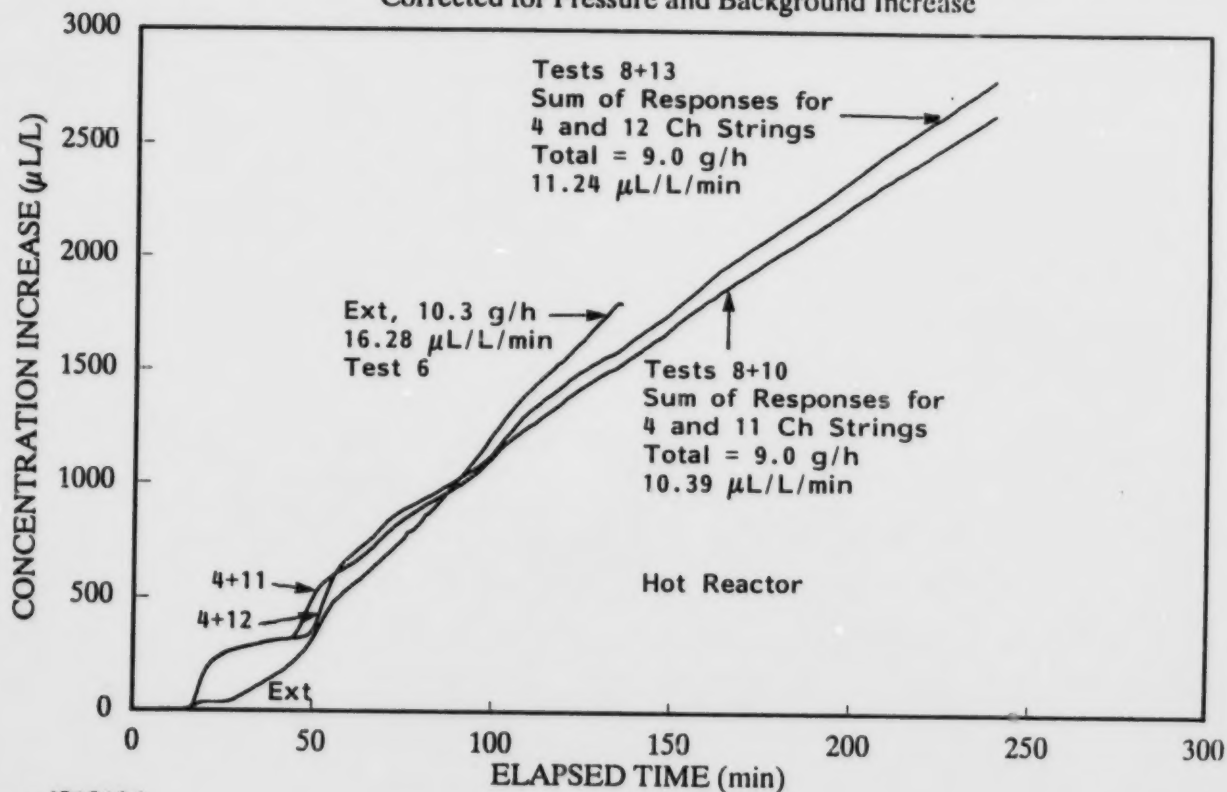
ad34&5v1

FIGURE 18

SUMMATION OF THE RESPONSES FOR FOUR AND ELEVEN OR TWELVE CHANNEL STRINGS APPROXIMATES THE EXTERNAL CIRCUIT RESPONSE AFTER THE INITIAL PERIOD (COLD REACTOR)

DARLINGTON AGS TESTS 6 and 8+10, 8+13

Corrected for Pressure and Background Increase



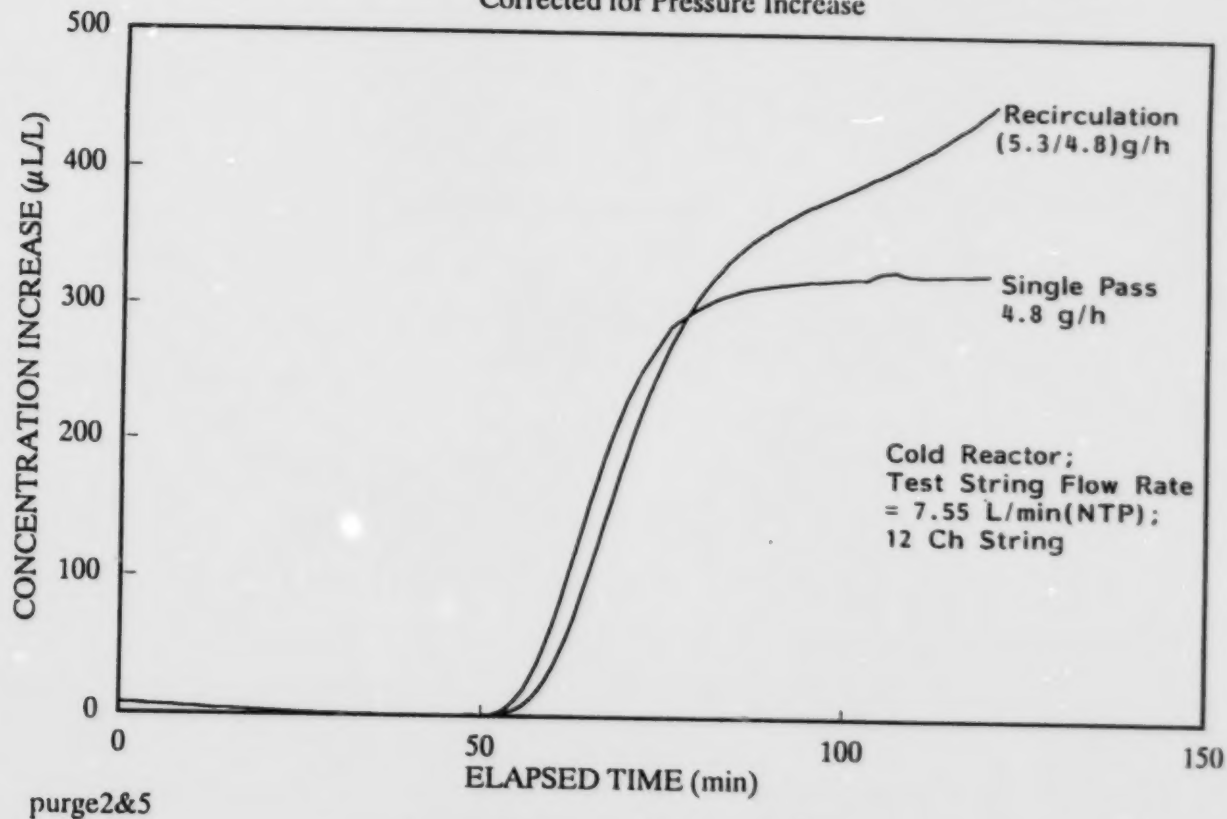
ad810136

FIGURE 19

SUMMATION OF THE RESPONSES FOR THE FOUR AND ELEVEN OR TWELVE CHANNEL STRINGS APPROXIMATELY THE EXTERNAL CIRCUIT RESPONSE AFTER THE INITIAL PERIOD (HOT REACTOR)

DARLINGTON AGS TESTS 2 and 5

Corrected for Pressure Increase



Test String Inlet/Outlet Pressure	Flow Rate at Actual Pressure
44/25 kPa(g)	5.64 L/min
35/17	6.00

FIGURE 20

THE INITIAL RESPONSES FOR RECIRCULATION AND SINGLE PASS OPERATION ARE SIMILAR AT A SIMILAR INJECTION RATE AND TEST STRING FLOW RATES

(Figure 21), the final steady state concentration increase was measured at $238 \mu\text{L/L}$ which is similar to $245 \mu\text{L/L}$ calculated from the injection rate of 3.4 g/h (0.0635 L/min NTP) and the overall flow rate of 259 L/min(NTP) given by FISO. Assuming an overall flow rate of 14% greater results in poorer agreement with the concentration rise of $215 \mu\text{L/L}$.

As shown in Figure 20 for a cold reactor, the initial responses for recirculation and single pass purge mode operation were similar at similar string pressures and injection and test string flow rates.

As shown in Figure 21 for a hot reactor, the delay time for single pass operation was greater than with recirculation. This is believed to be due to two effects. Firstly, the pressure in the system was significantly higher during the purge test although the NTP flow rate during the purge was similar to the normal recirculation rate. This resulted in a lower actual string velocity and hence longer residence time. Secondly, from Figure 21 and also Figure 13 which shows a delayed signal with a cold reactor, there may have been a greater cooling effect with the purge gas than with the recirculating gas resulting in a lower volumetric flow rate and further delay in the first peak. It is recommended that the pressure in the system be controlled closely to the desired value during purge operations.

4.2.10 Rate of Rise of Concentration

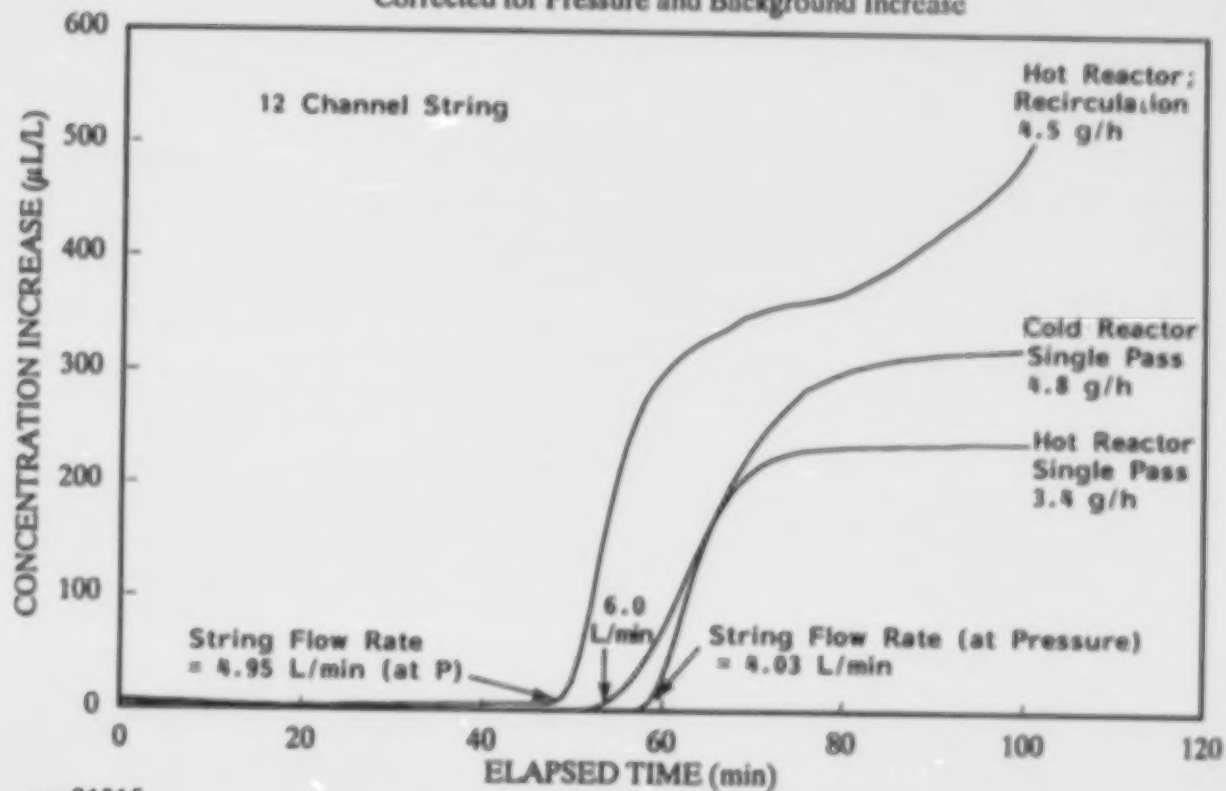
The raw data on the rate of rise of concentration are given in Appendix E and a summary is given in Tables E.1 to E.3. It is seen (Figures E-2 to E-15) that the rate of rise increases rapidly after the first response, hits a maximum value and then decreases.

The rate of rise of concentration was larger and the maximum rate occurred earlier when the reactor was hot. Also, the rate of rise was largest for the shortest string. The product of the string flow rate (actual conditions) and the time of occurrence of the maximum in the rate of concentration rise gave a value which closely approximated the channel volume. The hot test data suggested an average gas temperature in the four string channels of about 130°C and in the eleven and twelve channel strings of about 170°C .

Figure 22 shows that the concentration increase rate after the initial period of a simulated leak into the AGS was directly proportional to the leak rate and apparently not sensitive to reactor temperature.

DARLINGTON AGS TESTS 2, 13 and 15

Corrected for Pressure and Background Increase



prg21315

FIGURE 21

THE DELAY TIME FOR THE FIRST SIGNAL IS INCREASED WITH SINGLE PASS PURGE OPERATION AT SIMILAR NTP STRING FLOW RATES DUE TO HIGH SYSTEM PRESSURE

DARLINGTON AGS TESTS

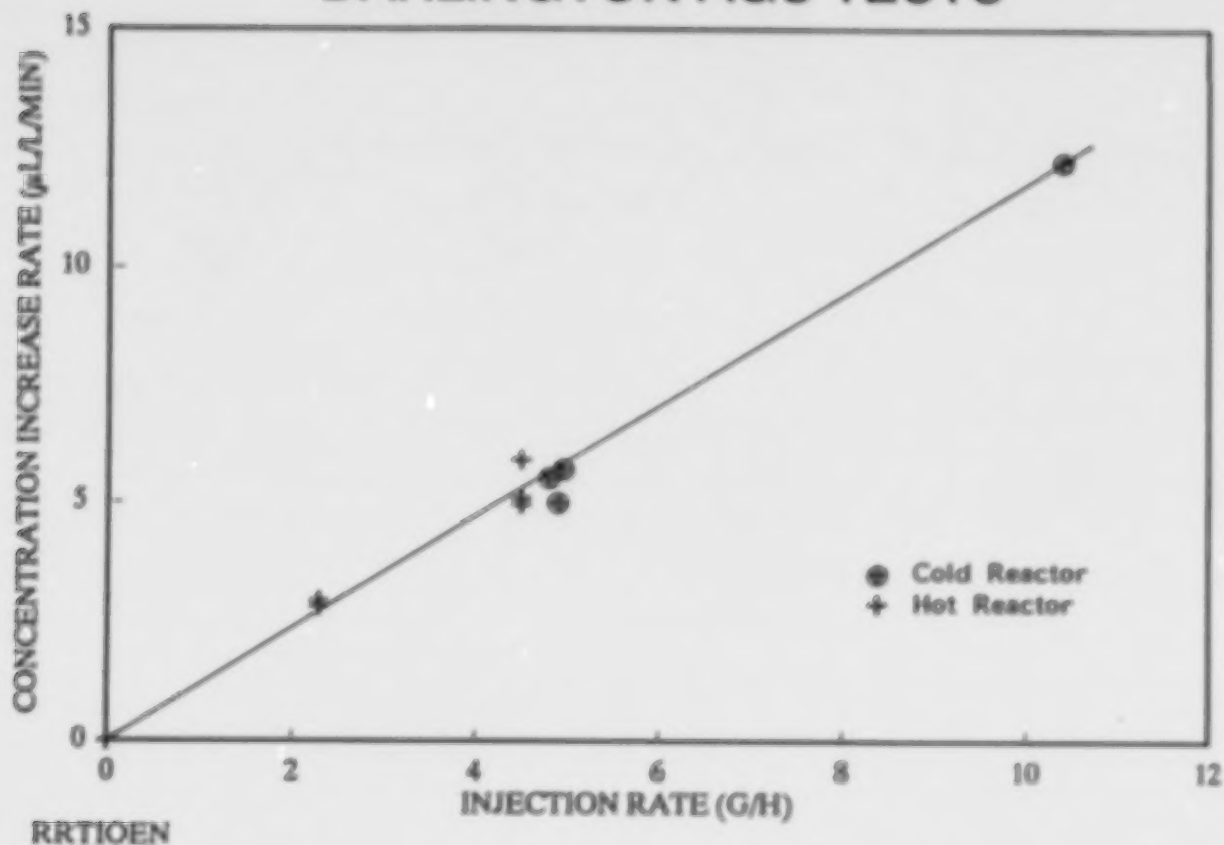


FIGURE 22

THE CONCENTRATION INCREASE RATE AFTER THE INITIAL PERIOD OF A "LEAK" IS DIRECTLY PROPORTIONAL TO THE "LEAK" RATE

DARLINGTON AGS TESTS

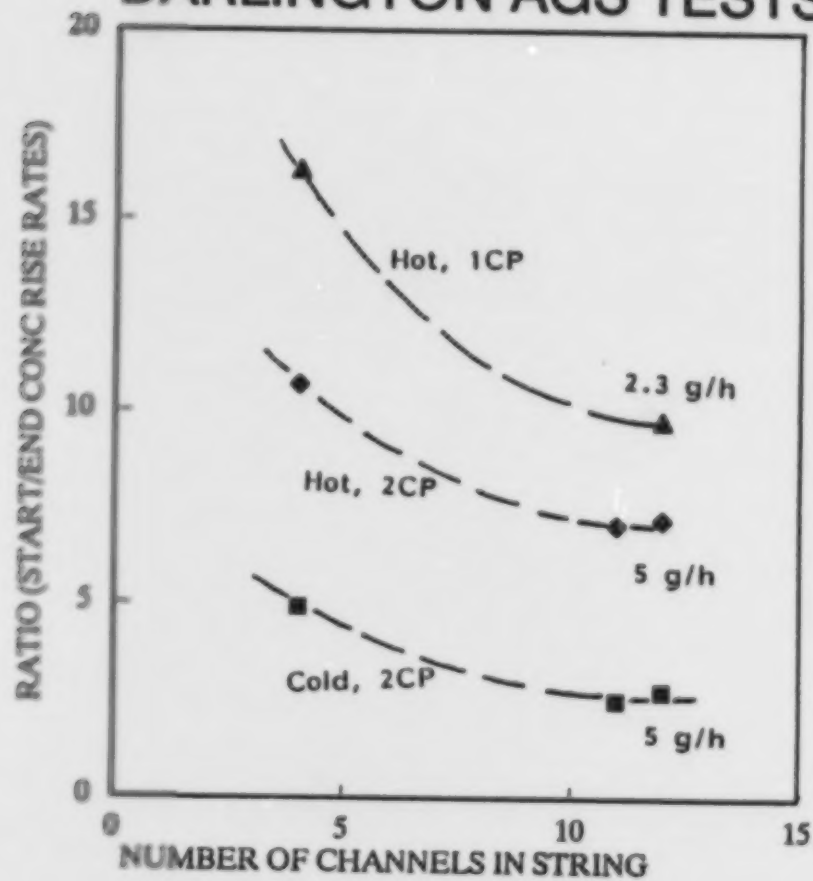


FIGURE 23

THE HIGHER THE MAXIMUM/STEADY STATE CONCENTRATION
RISE RATE, THE CLOSER THE LEAK IS TO THE
END OF THE STRING

DARLINGTON AGS TESTS

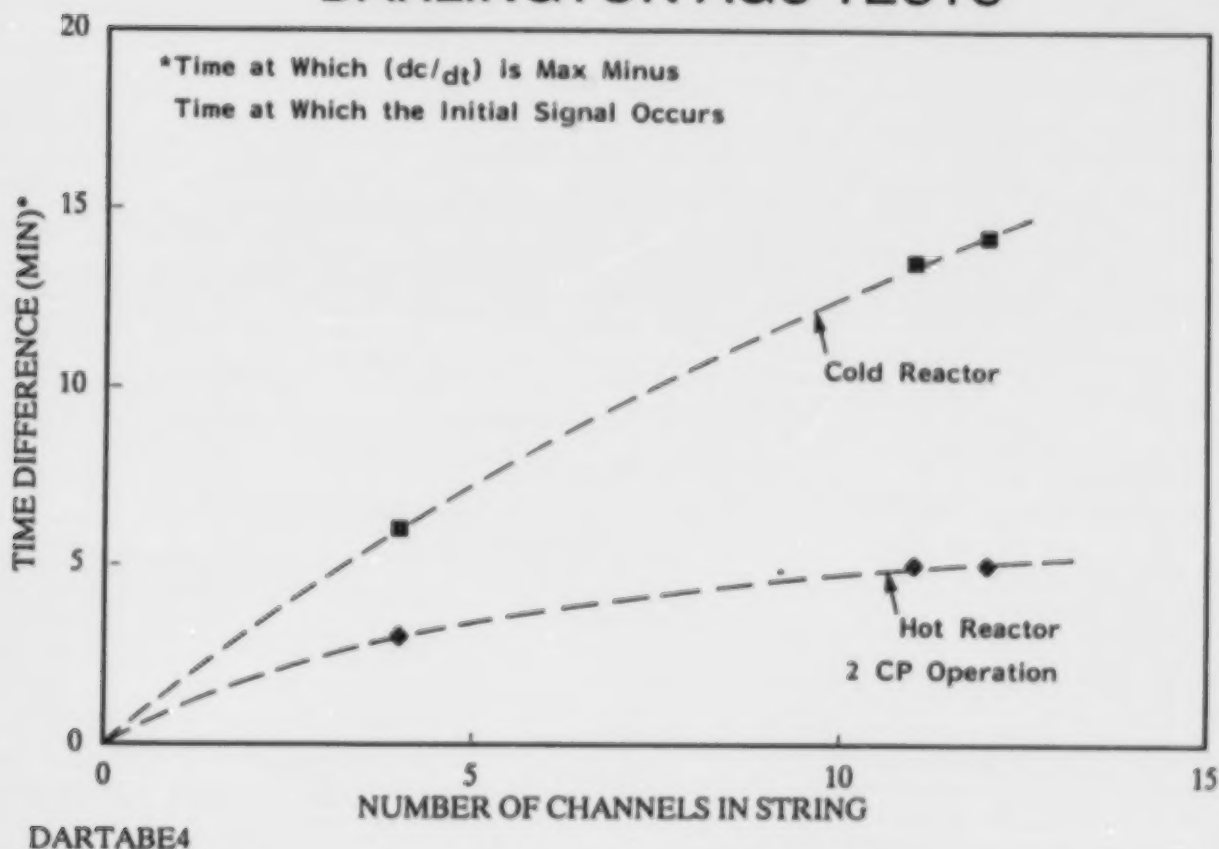


FIGURE 24

THE SMALLER THE TIME DIFFERENCE BETWEEN THE INITIAL SIGNAL AND THE TIME OF OCCURRENCE OF THE MAXIMUM IN THE CONCENTRATION RISE RATE, THE CLOSER THE LEAK IS TO THE END OF THE STRING

4.2.11 Leak Location

As discussed above, the slope of the concentration versus time graph increased to a maximum during the initial period (Figures E-2 to E-15). Also, during the final steady state period, the slope was constant. The ratio of the maximum rate of rise of concentration to the steady state rate of rise is plotted against the string length in Figure 23. The ratio is seen to be dependent on the reactor temperature and the number of compressors running. It is likely that the effect on this ratio of the leak rate which is directly proportional to the steady state rate of concentration rise has been factored out. Figure 23 shows that the greater the value of the ratio, the closer the leak is to the end of a string of channels. It is recommended that future tests consider injection into a string at one and two channels from the exit and into an eight channel string.

As suggested by J. Kenchington/personal communication(1990)/, the difference between the times of occurrences of the initial signal and of the maximum in the rate of rise of concentration is plotted against string length in Figure 24. It is seen that the time difference is smaller the shorter the string, i.e., the closer the leak is to the end of the string especially for a cold reactor. For the hot reactor, the dependence is weaker because readings were only taken every minute and the error in the differential time is large. It is recommended that future tests consider frequent sampling of the meter readings to better define the curve for a hot reactor.

5.0 CONCLUSIONS AND RECOMMENDATIONS

- 5.1 The station dew point meters read low by about five to ten degrees for both cold and hot tests although they were calibrated with heavy water.

Recommendation 1. It was recommended that the sensors be recalibrated and the electronics be correctly adjusted for field and control room agreement. This has been completed.

- 5.2 The MCM meter was the only instrument giving an accurate indication of the amount of water present and this was in terms of concentration. Concentration versus time curves were linear after the initial period of step changes in the AGS response. The slope of the curve was proportional to the simulated leak rate. Hence, an increase in the slope of a concentration versus time curve during a leak would indicate an increase in the leak rate. However, at the start of a leak, the dew point indication was the more sensitive parameter.

- 5.3 Accurately calibrated MCM and Panametrics hygrometers in series can be used to rapidly indicate whether light water or heavy water species predominate in the AGS, i.e., the presence of an end shield cooling leak.
- 5.4 As expected, the delay time for appearance of the injected water increased with string length. The delay time was shorter for a hot reactor than for a cold reactor probably as a result of a higher velocity in the annuli and reduced adsorption. The delay time for single pass purge operation increased as operating pressure increased at the same mass flow rate.
- 5.5 The slope of the concentration versus time curve during the initial response(initial slope) increased with increased reactor temperature. It also increased with reducing string length especially for a cold reactor. The final steady state slope was proportional to the simulated leak rate and independent of reactor temperature.
- 5.6 The initial and final slopes of the concentration versus time curves were indicative of the location of the leak. For example, the larger was the ratio of the initial slope to the final slope, the closer the leak was to the end of a string. Also, the smaller the difference in times between the first indication of an increase and the occurrence of the maximum in the concentration increase rate, the closer the leak was to the end of a string of channels.

Recommendation 2. It is recommended that future tests consider injection into a string at one and two channels from the exit and in an eight channel string to extend the data base to cover additional string lengths over which leaks are also possible.

Recommendation 3. It is recommended that future tests consider frequent sampling of the meter readings for a more accurate determination of the time difference.

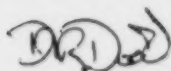
- 5.7 Light water predominated in the AGS at the end of a purge. For the hot tests only, the heavy water concentration increased slowly in the system prior to injection. The rate of increase was constant at about 0.8g/h of D_2O . At the end of the injection tests, the water species was predominantly D_2O .

Recommendation 4: It is recommended that helium gas be also injected together with water vapor in future tests to determine the importance of adsorption on the delay time for the appearance of the first signal and the rate of rise of concentration.

- 5.8 The total flow rate indication of the main flow rotameter (F150) was about 14% lower than the value obtained from the rotameters on the 48 strings.

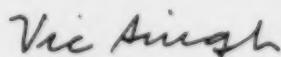
Recommendation 5: It is recommended that the calibration of the main flow rotameter be checked.

Approved by:



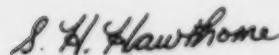
D.J.R. Dodd
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V.P. Singh
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S.H. Hawthorne
Supervising Engineer
Process Chemistry

6.0 REFERENCES

V.P.Singh and S-D.Chang, Pickering Annulus Gas Moisture Injection Tests, Report No 87-254-H, Ontario Hydro Research Division (1988).

APPENDIX A

DEW POINT DATA

The dew point data for tests 1 to 15 (tests 7,11,12 were cancelled) are given in Figures A.1 to A.15.

A.1 MCM CORRECTION (HOT TESTS)

It was found that the MCM sensor read correctly during the cold tests and at the start of the first hot test (test 6) but had shifted its calibration downwards by about 1°C at -5°C dew point by the end of the test. On return of the instrument to Research Division, it was found that the heated brass sensor block was entirely coated with black sulphide.

The data for all the hot tests were reviewed (see below) resulting in small corrections being applied, i.e., about 2°C being added to the MCM reading at low dew point and 1°C at high dew point in tests 8 to 15. The exact correction applied is given by:

$$\text{MCM corrected} = \text{MCM raw} \times 0.958 + 0.949$$

For test 6, a partial correction was applied, i.e. below -14°C, add 0°C and at -5°C, add 1°C. The exact correction applied is given by:

$$\text{MCM corrected} = \text{MCM raw} \times 1.129 + 1.805$$

(For completeness, it is noted here that further corrections were made to the MCM data to subtract out the gradual background drift up in the system moisture concentration which occurred only during the hot tests as a result of system desorption, etc and to account for the carbon dioxide gas used as carrier for the injected heavy water. These are discussed in the sections on concentration measurements).

A.2 DEW POINT AT START OF TEST

Test dates, AGS purge times and data on the operation of the EG&G mirror hygrometer are given in Table A.1. These latter indicate the accuracy of the EG&G data to be expected depending on the time allowed for stabilization of the readings and depending on the isotopic species (light or heavy water or a mixture) in the surrounding gas versus the isotopic species on the mirror. Usually about two hours were allowed after rebalance so from a response time point of view, the data were accurate within 2°C at -30°C dew point and much better at -10°C.

The corrections given in Appendix B were used to generate Table A.2. This table shows that light water was the dominant species at the start of the cold tests but a light water/heavy water mixture was present at the start of several hot tests.

TABLE A.1 TEST DATES, START AND AGS PURGE TIMES, AND EG&G OPERATION

TEST NUMBER	DATE	AGS PURGE START TIME	PURGE END / RECIRC TIME	EG&G CLEANING TIME	EG&G RE-BALANCE TIME	AGS CONDITION AT REBAL TIME	TEST START / INJECT TIME	TEST FINISH TIME
1	MON 18 SEPT 1989	-16:05	17:42 17:30	14:00	14:00	-22C D.P. THEN AGS PURGE TO 17:42	18:30 DAYLIGHT SAVING TIME	23:00
5	TUES 19 SEPT	-23:30 MON	-02:00 TUES	12:43	12:43 21:00*	-30C D.P. -5C D.P.	13:33	22:30
2	WED 20 SEPT	-22:50 TUES	-01:30 WED	09:04	09:04	-33C D.P.	11:15	13:15
3	WED 20 SEPT	-13:55 WED	15:08 WED	NOT AT START	NOT AT START	- 1 HR PURGE AFTER TEST 2	16:00	24:00
4	THURS 21 SEPT	01:45	PRIOR TO 09:00	NOT AT START	08:45	-35C D.P.	11:00	20:20
=====								
6	THURS 23 NOV	? STANDARD	? TIME	08:45	08:45	-23C D.P.	11:00	13:14
8	FRI 24 NOV	?	PRIOR TO 09:00	09:00	09:00	-23C D.P.	13:21	17:25
9	SAT 25 NOV	17:30 FRI	08:20 TCP AT 09:50	08:40	08:50	-30C D.P.	11:00	18:06
10	SUN 26 NOV	18:30 SAT	08:25	08:40	08:40	-31C D.P.	11:10	16:24
13	MON 27 NOV	16:30 SUN PURGE AGA IN 09:00 MON	19:00 SUN 10:50 MON	09:05	09:15 D2O ON MIRROR AFTER REBAL	-16C D.P. THEN 1.5 HR PURGE	13:00	18:05
14	TUES 28 NOV	?	08:42	08:43	08:43 ALSO 16:16	-30C D.P. -11C D.P.	10:40	19:15
15	WED 29 NOV	19:15 TUES PURGE ON AGA IN 10:27	-23:20 TUES	11:28	11:28	-29C D.P.	13:20	16:00

* LOWER READINGS AFTER REBALANCING

NOTE: OHRD INSTRUMENTS WERE VALVED IN TO AGS SYSTEM OVERNIGHT DURING COLD TESTS
OHRD INSTRUMENTS WERE KEPT UNDER DRY CO2 OVERNIGHT DURING HOT TESTS.

DARLINGTON AGS TEST 1

Cold Tests

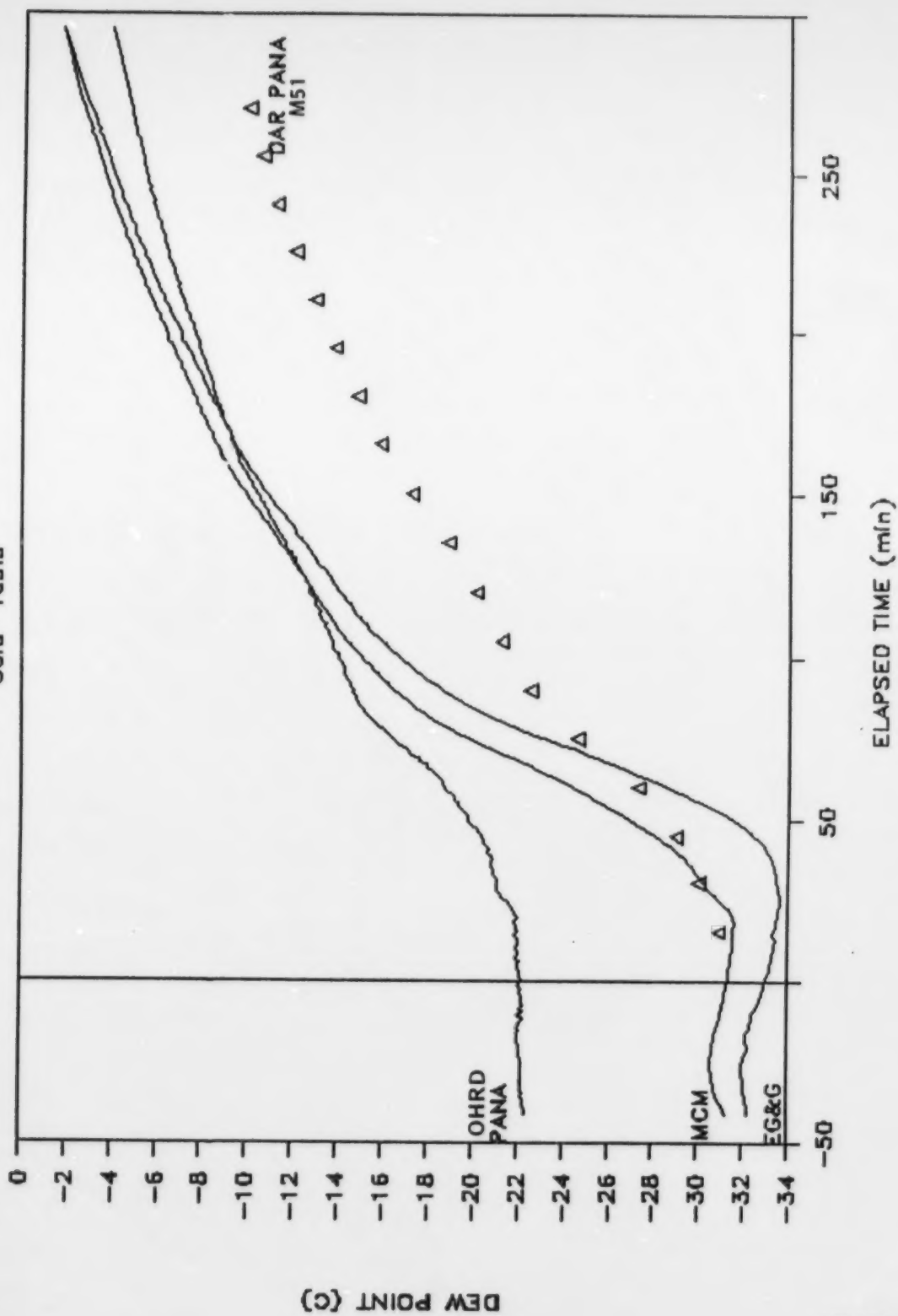
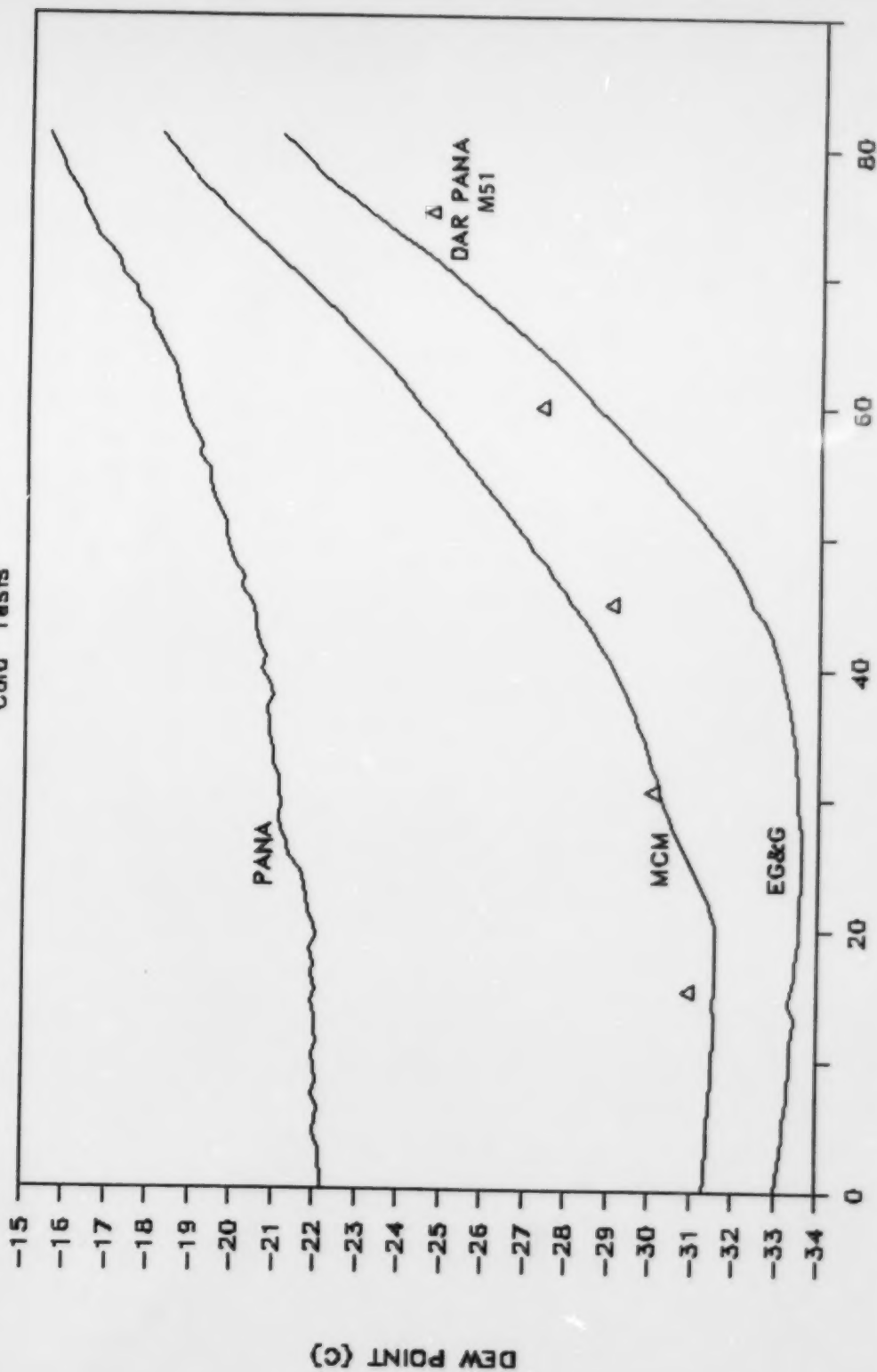


FIGURE A-1(a)

DEW POINT VS TIME FOR TEST 1

DARLINGTON AGS TEST 1

Cold Tests



ELAPSED TIME (min)

FIGURE A-1(b)

INITIAL DEW POINT RESPONSE FOR TEST 1

DEW POINT (C)

DARLINGTON AGS TEST 2

Cold Tests

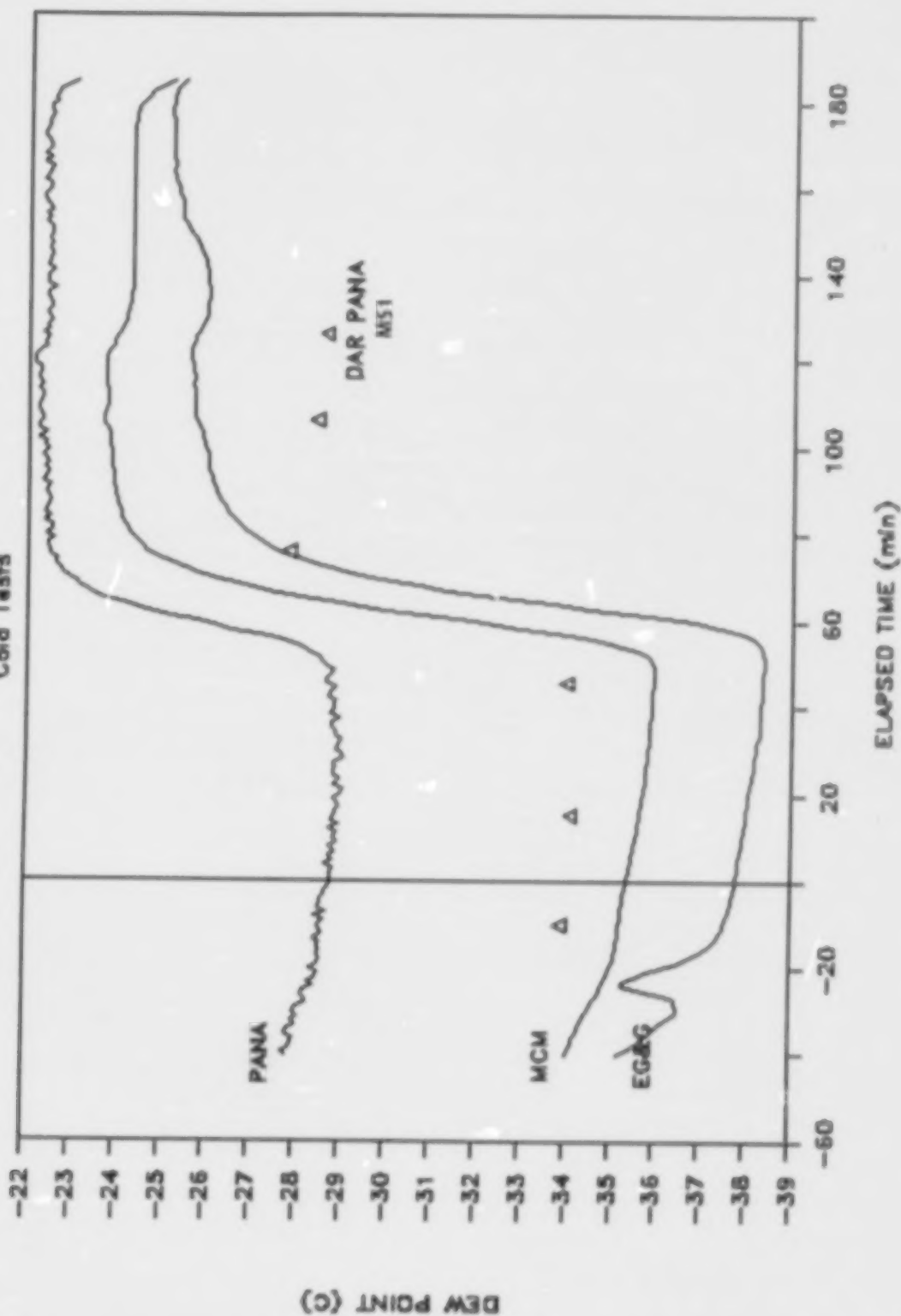
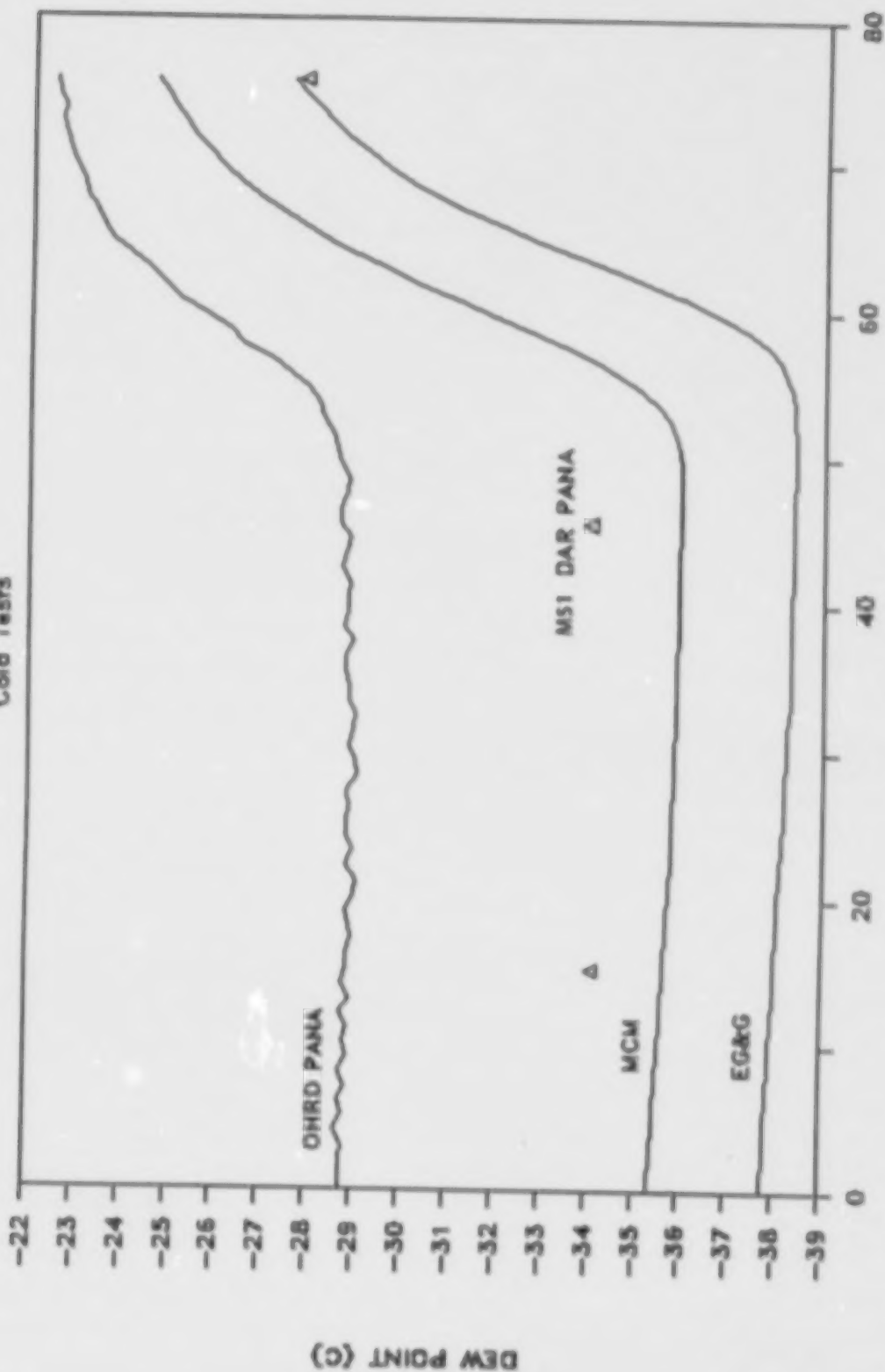


FIGURE A-2(a)
DEW POINT VS TIME FOR TEST 2

DARLINGTON AGS TEST 2

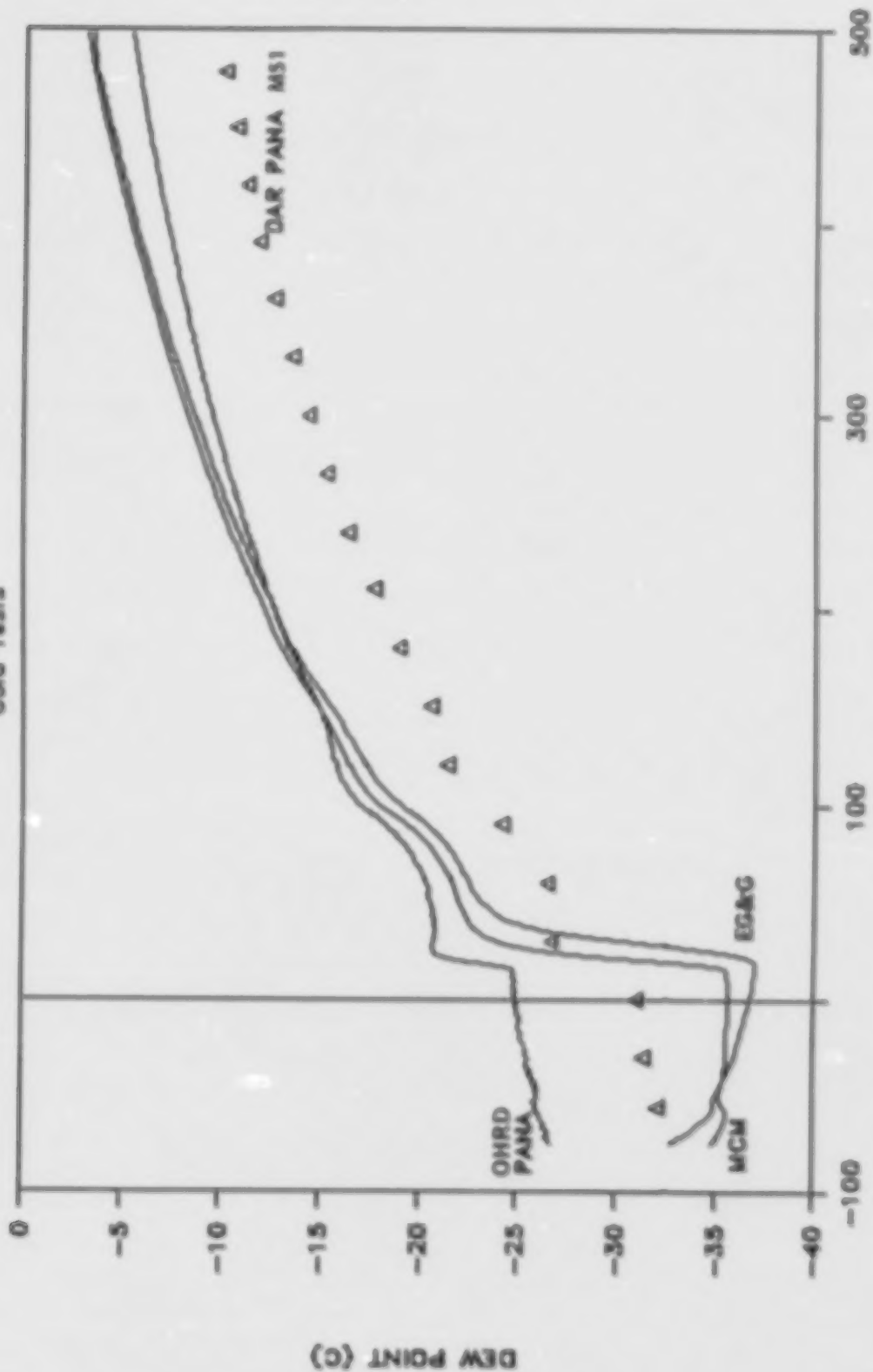
Cold Tests



ELAPSED TIME (min)
FIGURE A-2(b)
INITIAL DEW POINT RESPONSE FOR TEST 2

DARLINGTON AGS TEST 3

Cold Tests



ELAPSED TIME (min)

FIGURE A-3(e)

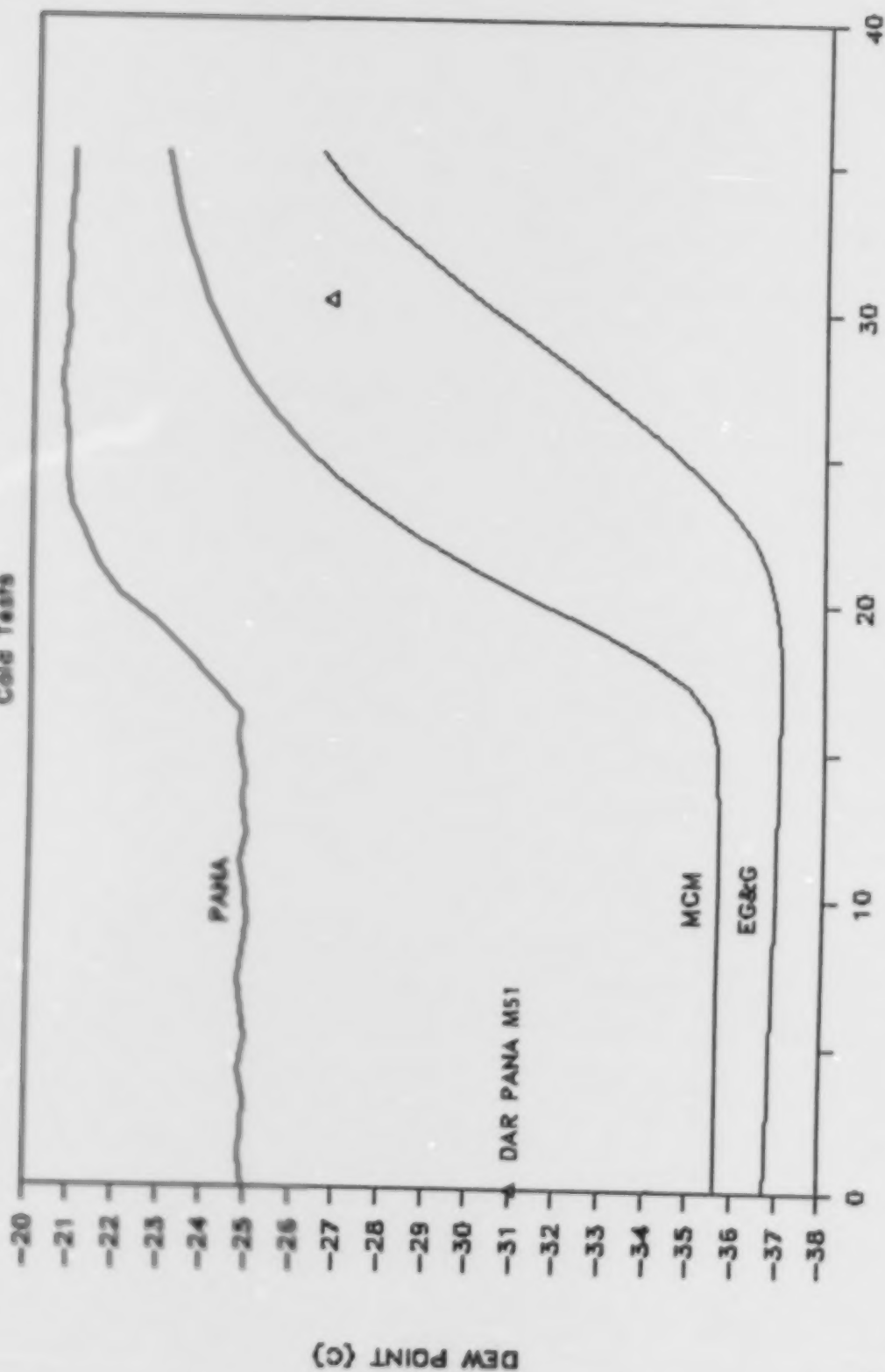
DEW POINT VS TIME FOR TEST 3

DR-146281

20-298

DARLINGTON AGS TEST 3

Cold Tests



ELAPSED TIME (min)

FIGURE A-3(b)

INITIAL DEW POINT RESPONSE FOR TEST 3

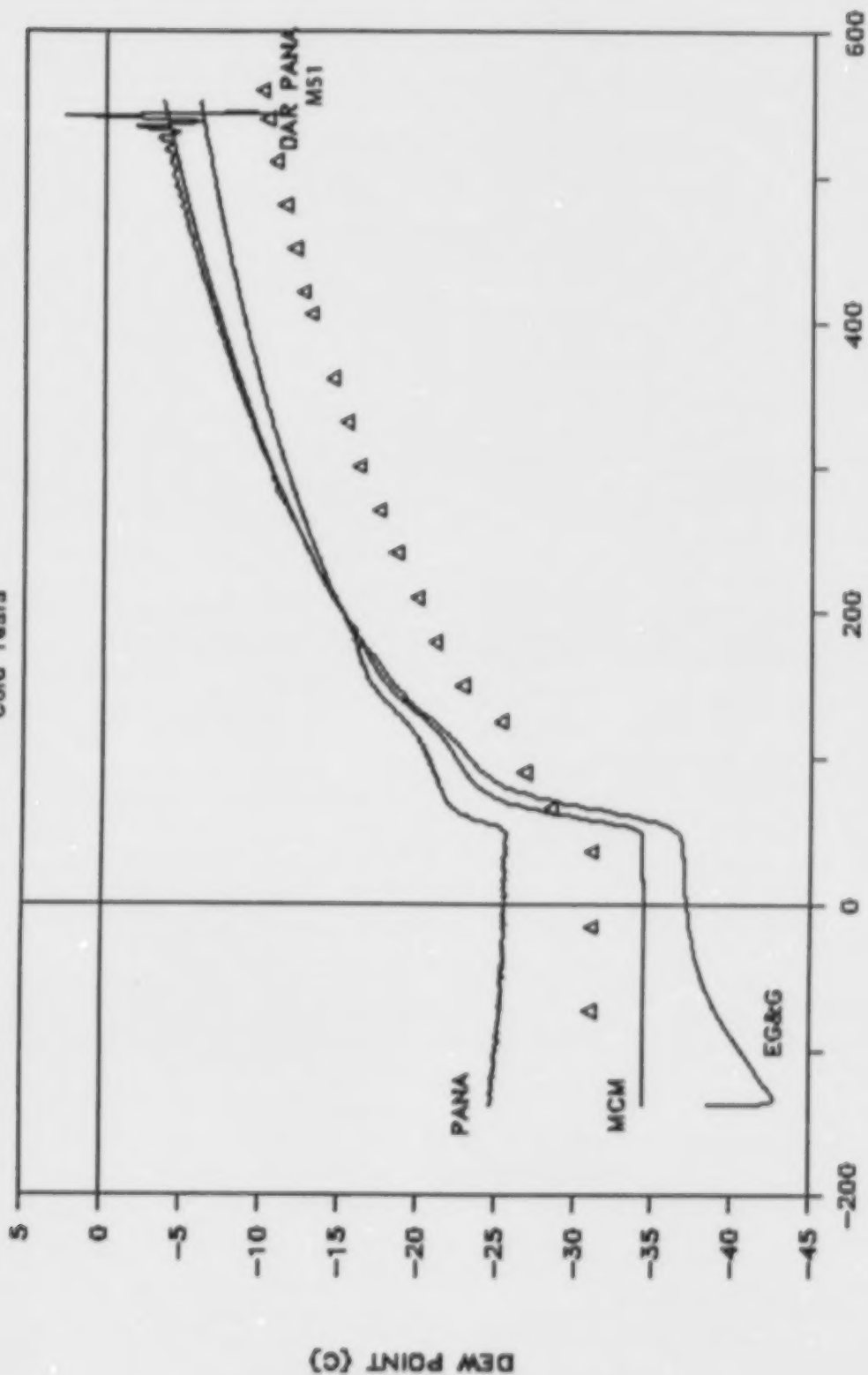
DEW POINT (C)

184342-RD

90-298

DARLINGTON AGS TEST 4

Cold Tests



ELAPSED TIME (min)
FIGURE A-2(a)
DEW POINT VS TIME FOR TEST 4

DARLINGTON AGS TEST 4

Cold Tests

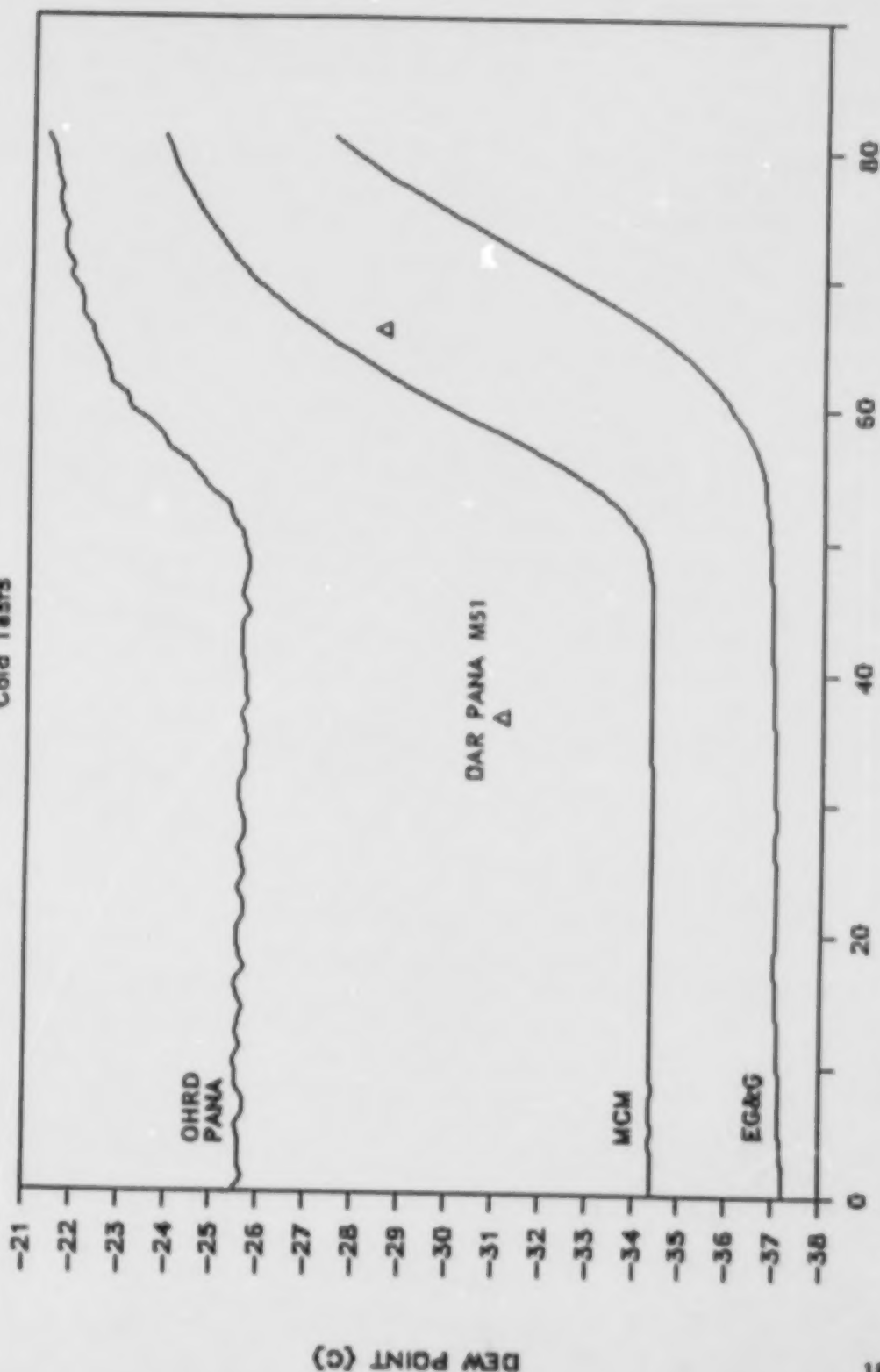


FIGURE A-4(b)

INITIAL DEW POINT RESPONSE FOR TEST 4

DEW POINT (C)

01V

DR-443481

90-298

DARLINGTON AGS TEST #
ANNULUS GAS SYSTEM 34880

Standard Time
2Y 19:52:35 21-SEP-89

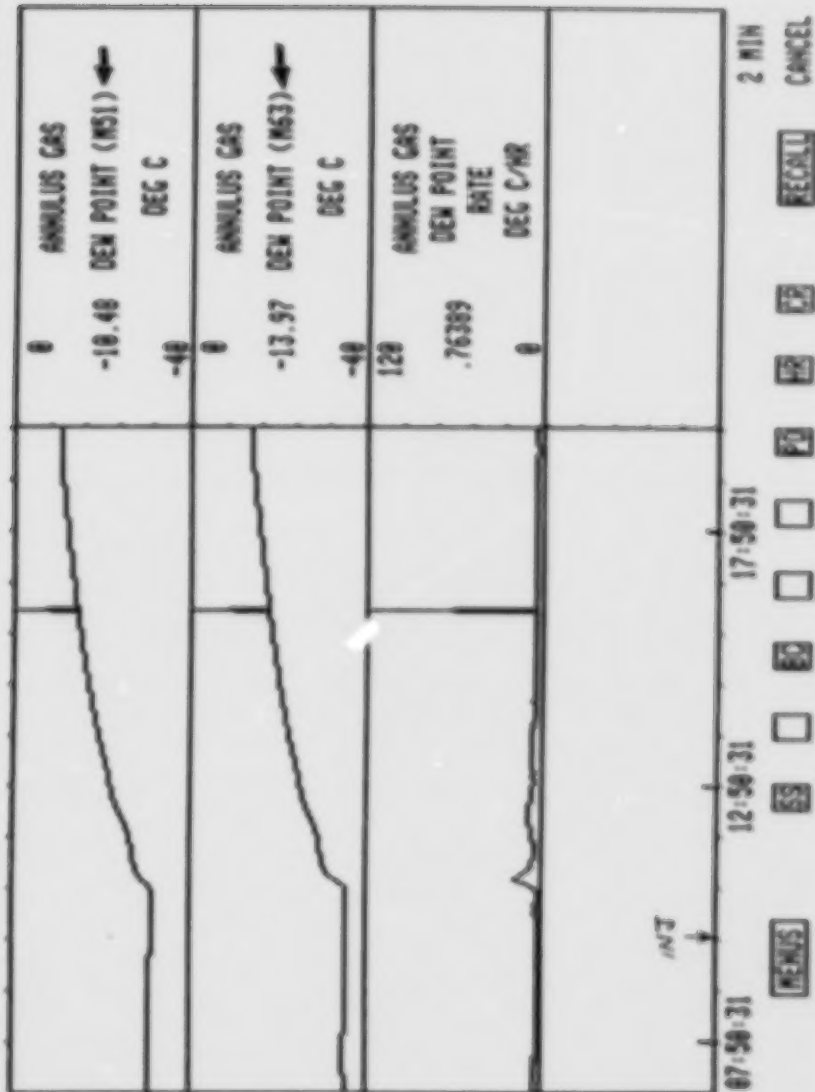


FIGURE A-4(c)
CONTROL ROOM PRINT OUT FOR TEST #

DARLINGTON AGS TEST 5

Cold Tests

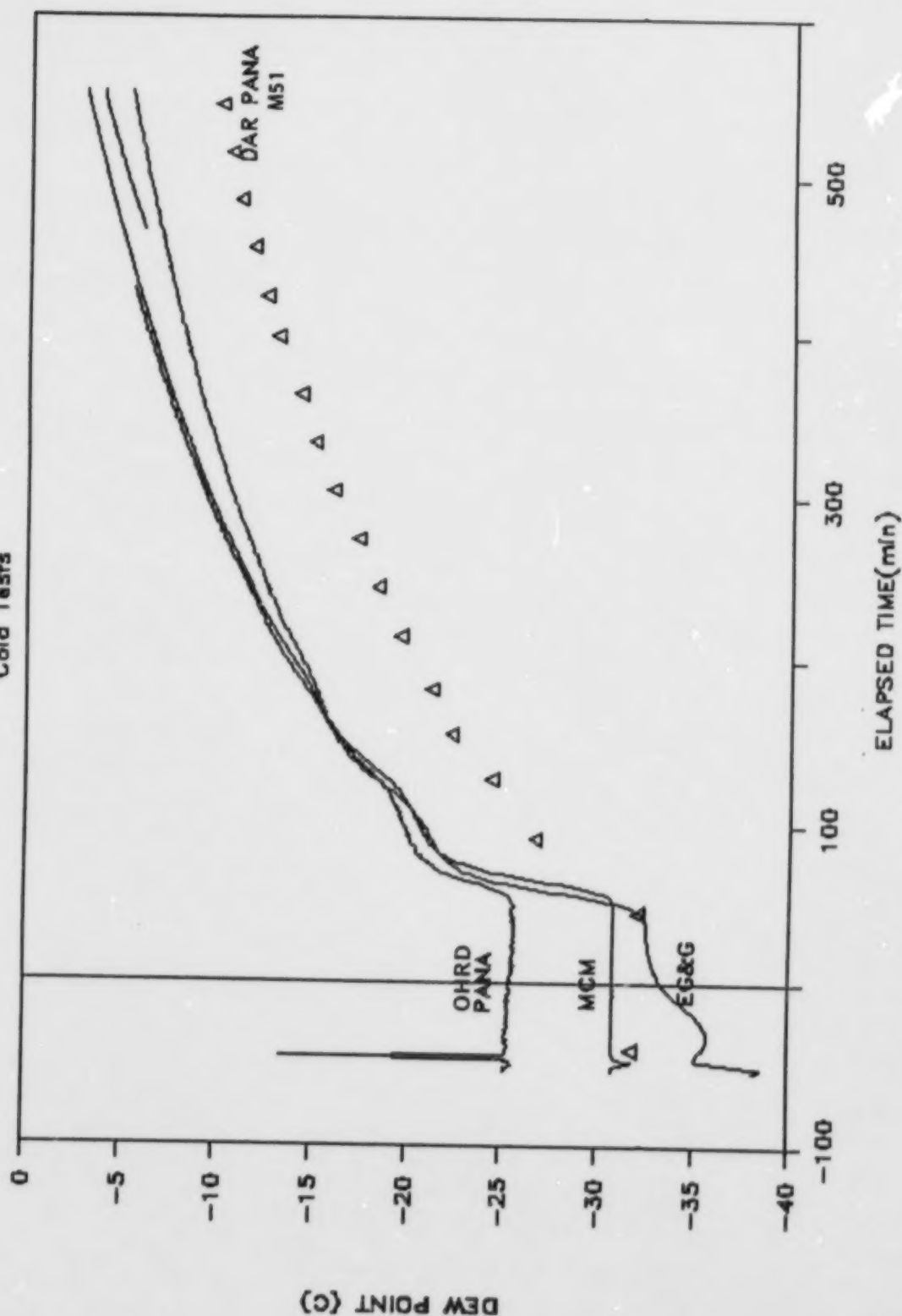


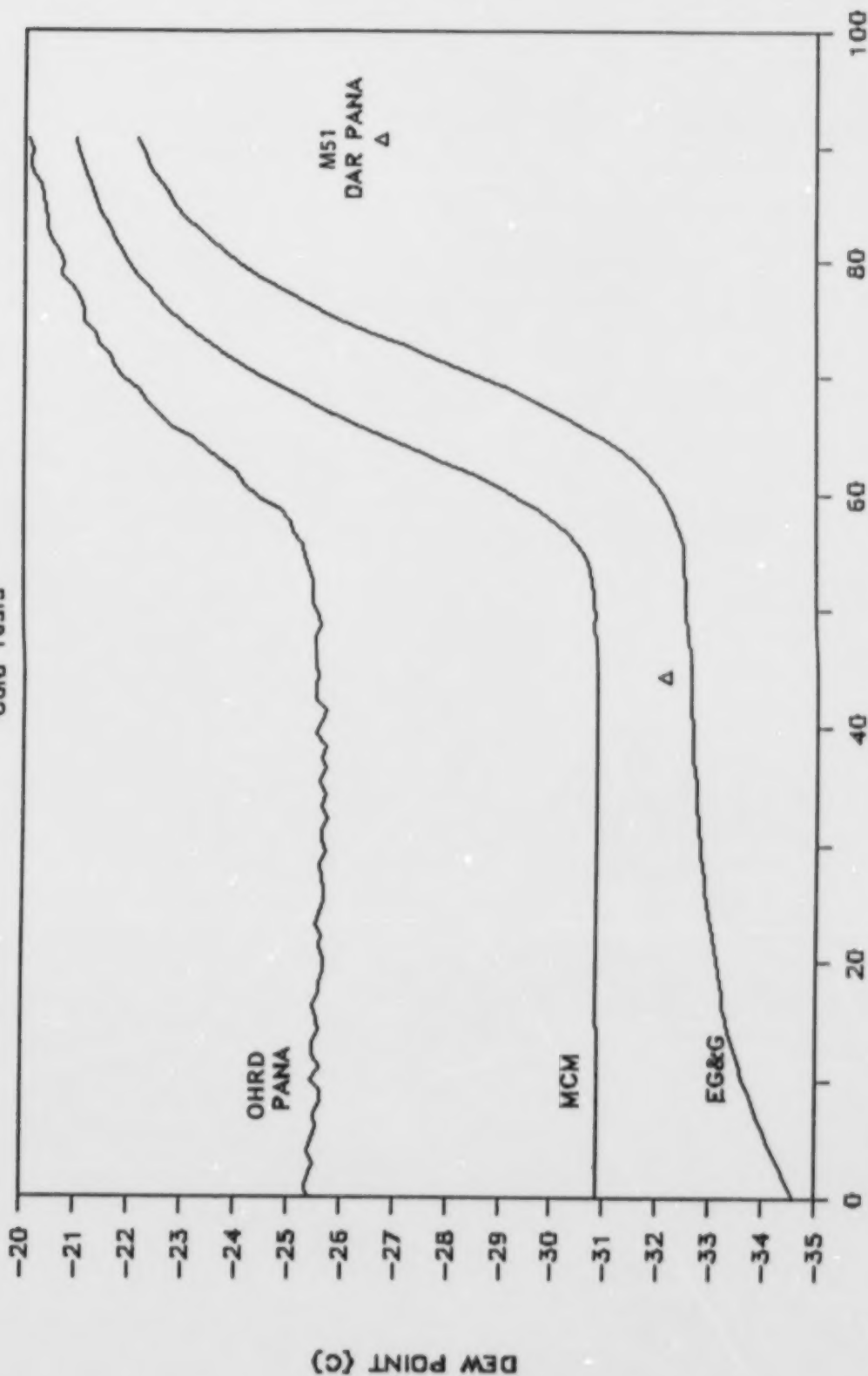
FIGURE A-5(a)
DEW POINT VS TIME FOR TEST 5

184346-RD

90-298

DARLINGTON AGS TEST 5

Cold Tests



ELAPSED TIME(min)

FIGURE A-5(b)

INITIAL DEW POINT RESPONSE FOR TEST 5

DARLINGTON AGS TEST 6

RAW DATA (hot tests)

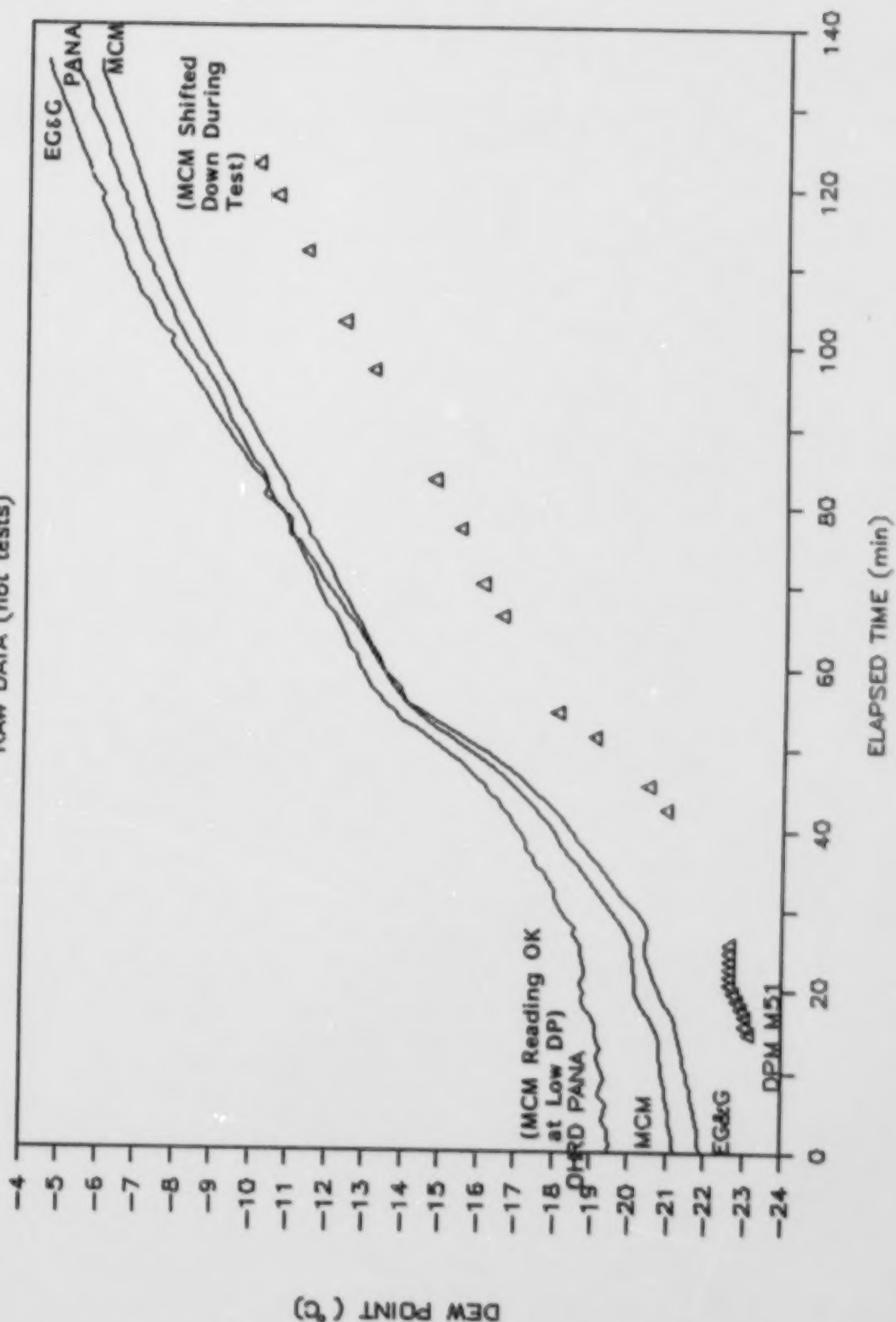
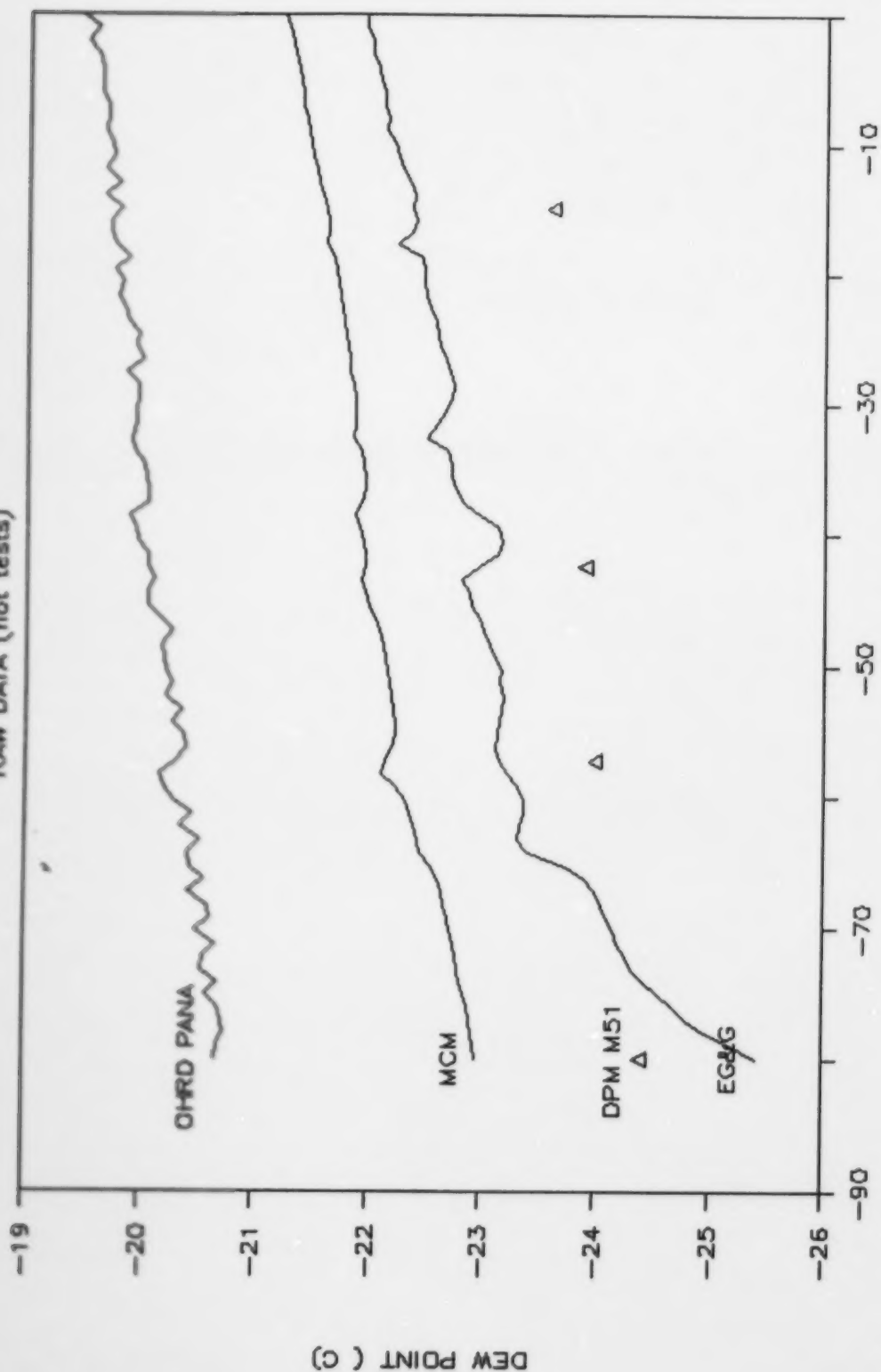


FIGURE A-6(a)
DEW POINT VS TIME FOR TEST 6 (RAW DATA)

DARLINGTON AGS TEST 6

RAW DATA (hot tests)



ELAPSED TIME (min)

FIGURE A-6(b)

INCREASING SYSTEM D.P. BEFORE INJECTION TEST 6

184349-RD

90-298

DARLINGTON AGS TEST 6 MCM PARTIAL CORRECTION

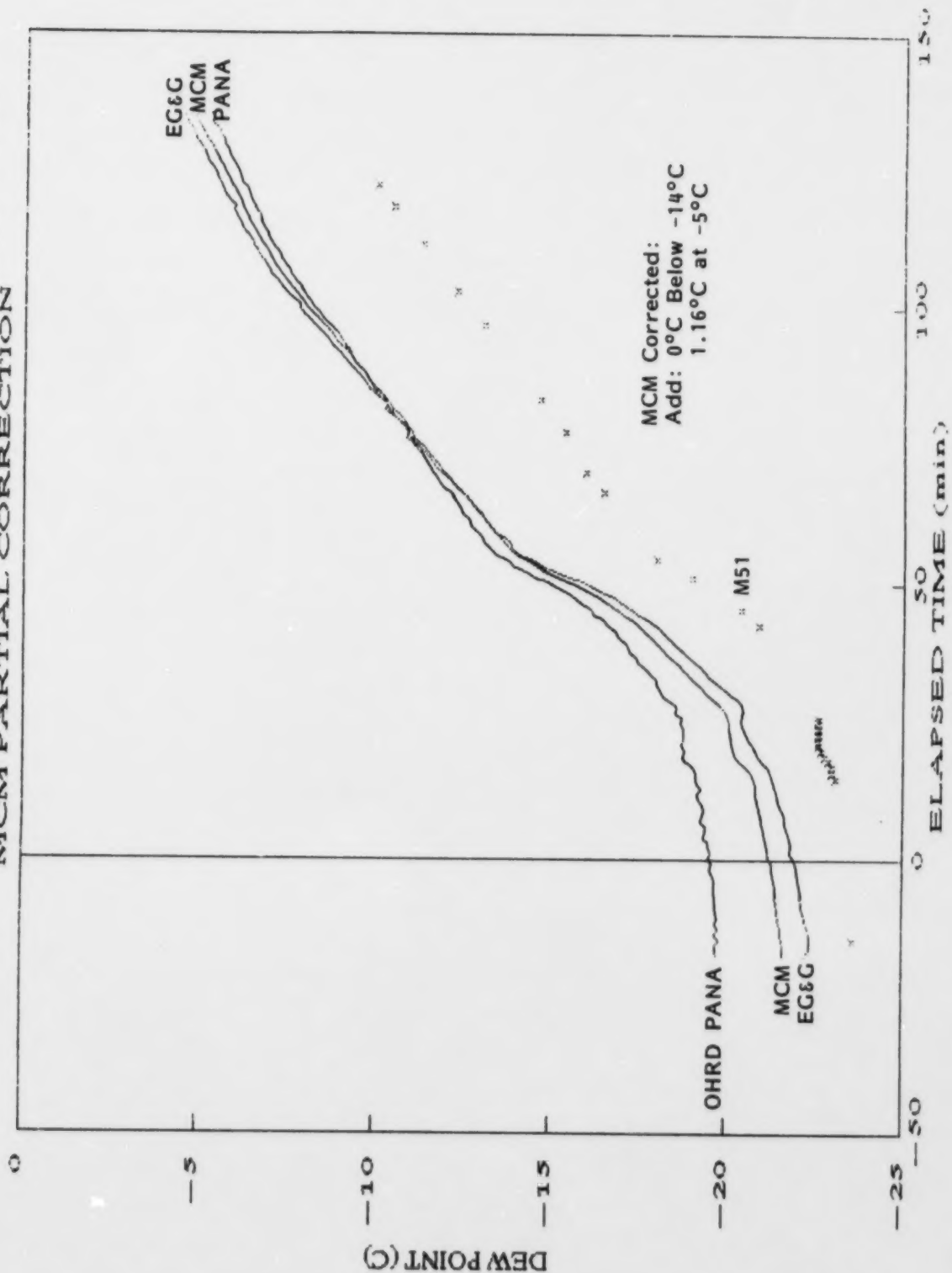


FIGURE A-6(c)
DEW POINT VS TIME FOR TEST 6 (MCM CORRECTED)

DARLINGTON AGS TEST 8

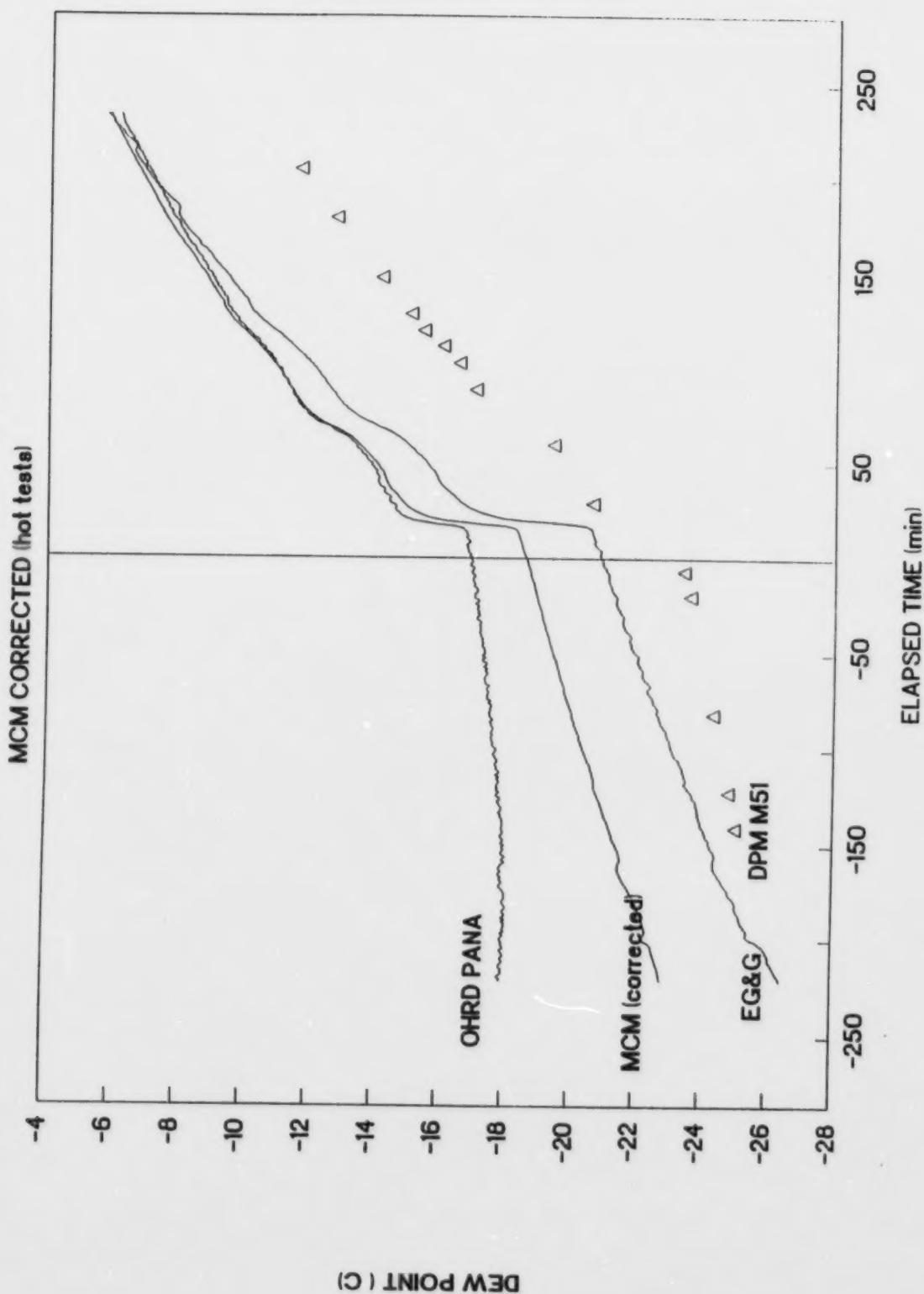
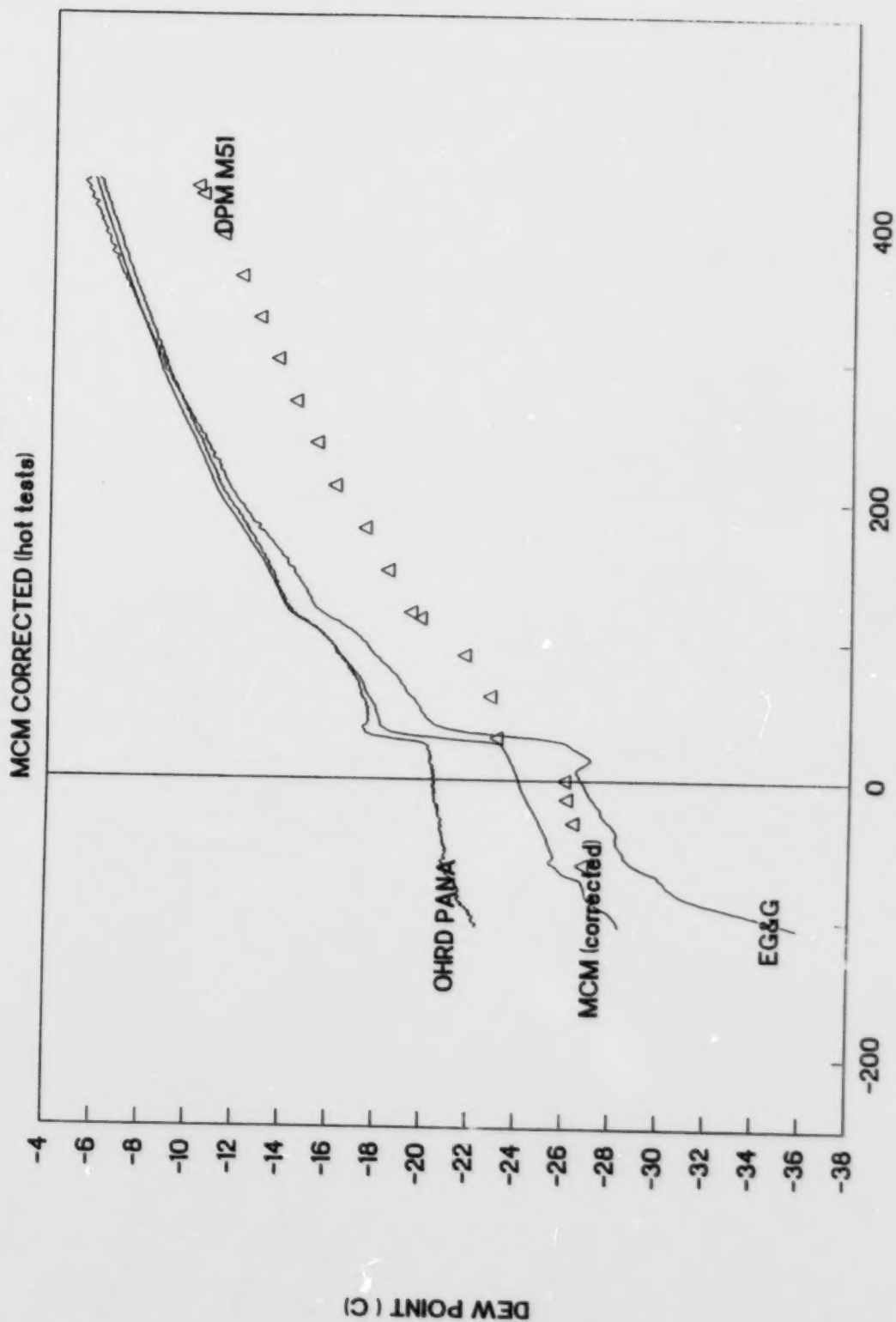


FIGURE A-8
DEW POINT VS TIME FOR TEST 8

DARLINGTON AGS TEST 9



DEW POINT VS TIME FOR TEST 9
FIGURE A-9

DARLINGTON AGS TEST 10

MCM CORRECTED (hot tests)

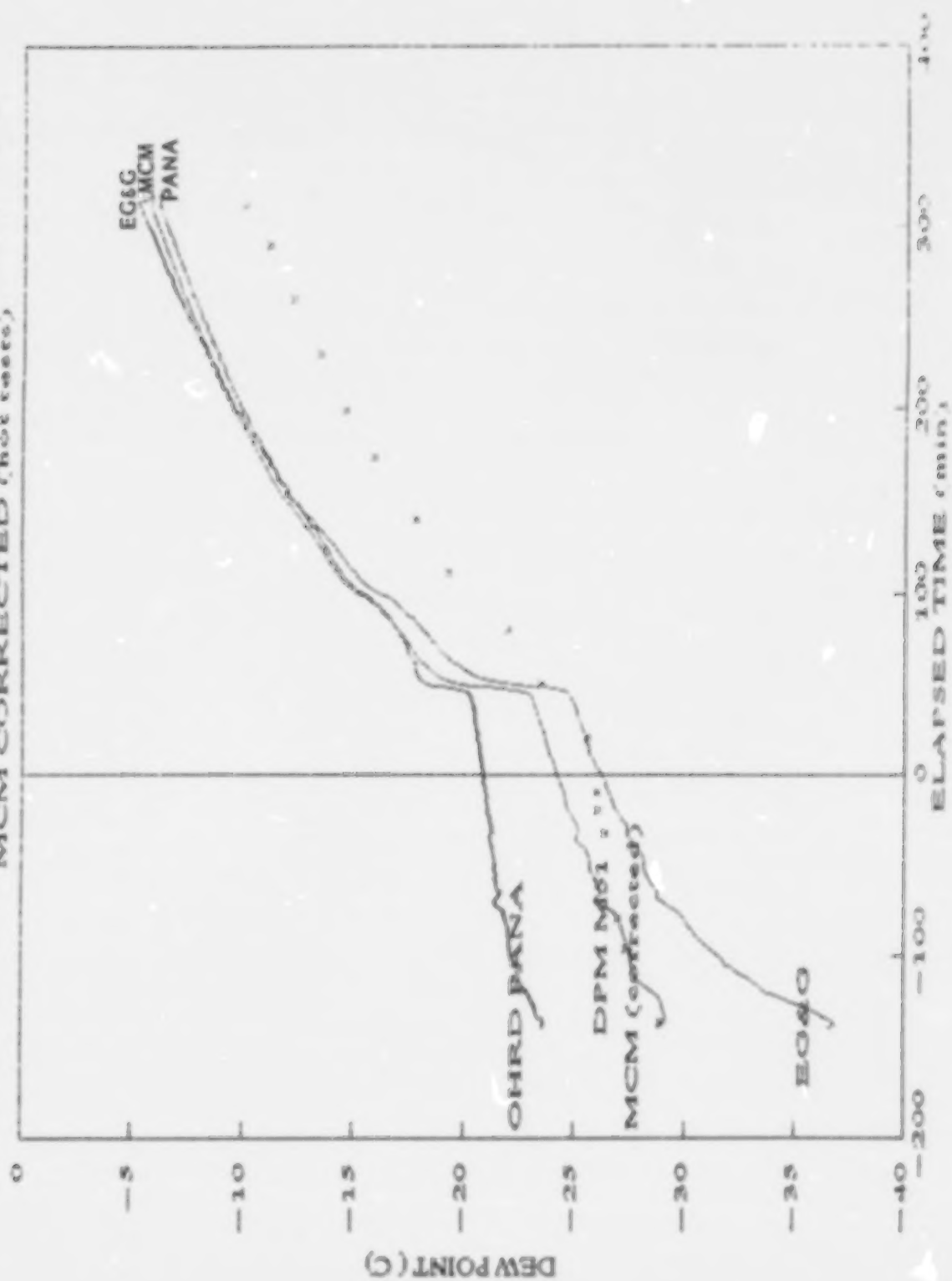


FIGURE A-10

DEW POINT vs TIME FOR TEST 10

DARLINGTON AGS TEST 13

MCM CORRECTED (hot tests)

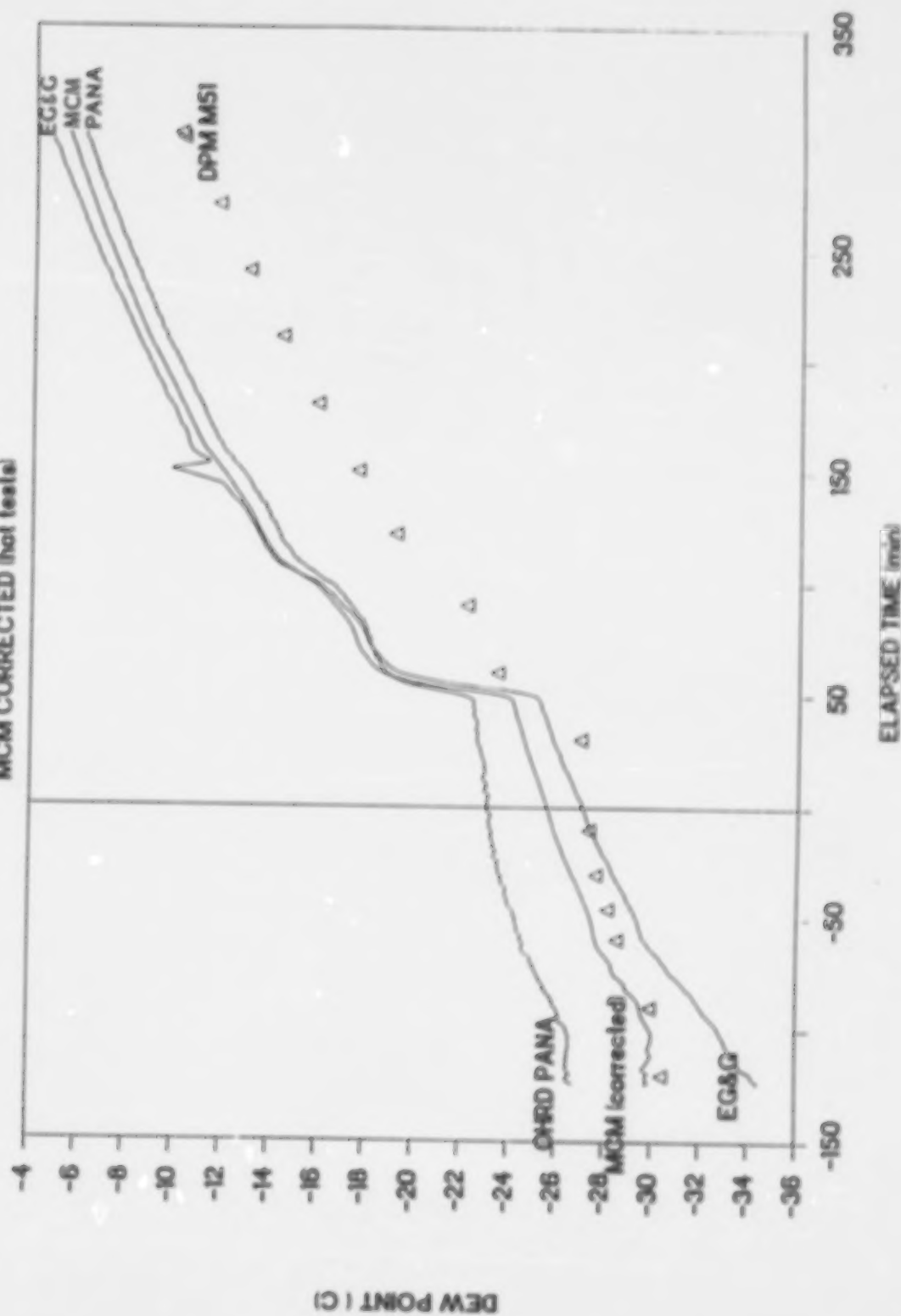


FIGURE A-13
DEW POINT VS TIME FOR TEST 13

DARLINGTON AGS TEST 14

MCM CORRECTED (not tests)

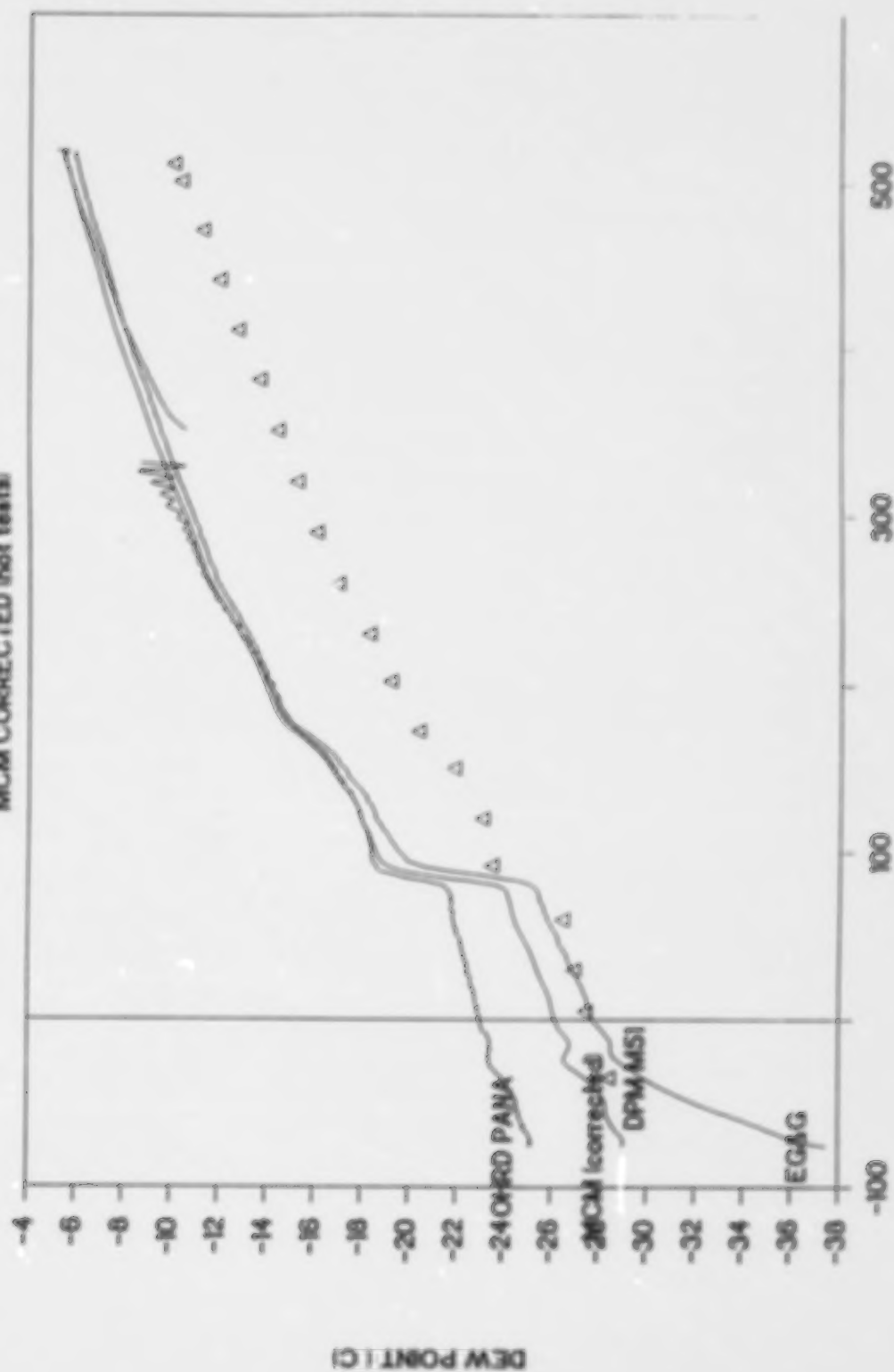


FIGURE A-14

DEW POINT VS TIME FOR TEST 14

DARLINGTON AGS TEST 15

MCM CORRECTED (hot tests)

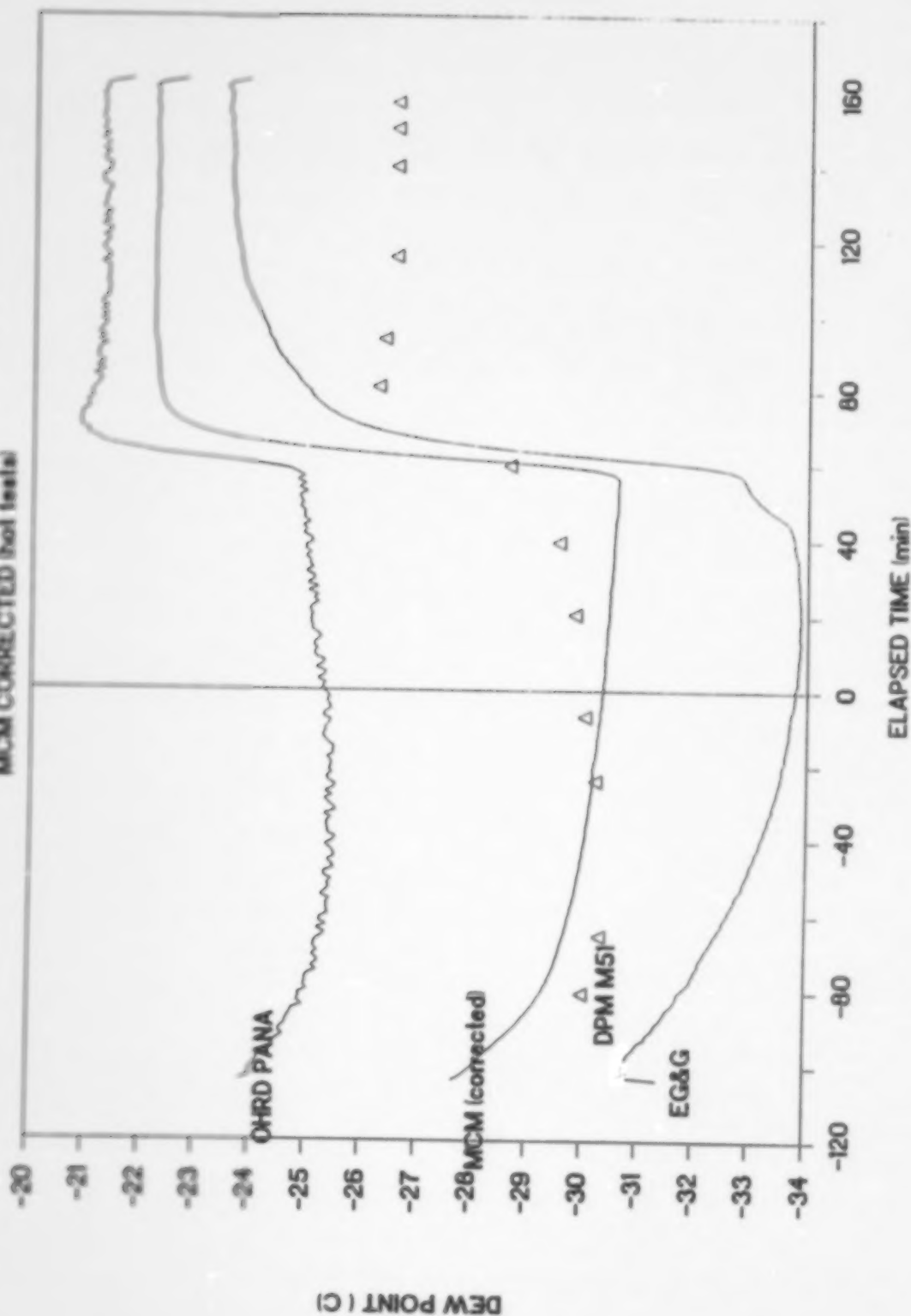


FIGURE A-15
DEW POINT VS TIME FOR TEST 15

APPENDIX B

METER CORRECTIONS FOR DIFFERENT CALIBRATION AND OPERATING CONDITIONS

Singh(1988) has given data for correcting the meter reading to true dew point if the isotope of water being measured is different from the isotope used to calibrate the instrument, i.e., generate the electrical output signal versus dew point and set up the electronics for direct dew point readout.

An empirical correction graph is given in Figure B.1 for the Panametrics meter over the range shown. This does not include corrections for different carrier gases (e.g. carbon dioxide and nitrogen) during calibration and measurement.

For the MCM which gives the same reading for the same vapor pressure whether of light or heavy water, a similar graph is given in Figure B.2. As an approximation, 3 degrees should be added to the MCM reading if it was calibrated with light water but used to measure heavy water and three degrees should be subtracted from the MCM reading if it was calibrated with heavy water and used to measure light water. Alternatively, if the MCM was calibrated for isotope 1 and used to measure isotope 2, the true dew point may be obtained by calculating the vapor pressure at the indicated dew point temperature from the log pressure vs 1/T curve for isotope 1 and then obtaining the true dew point by substituting the pressure into the log pressure vs 1/T curve for isotope 2. The vapor pressure of light water frost in the range 0 to -40°C is given by:

$$\log e P(\text{Pascal}) = 28.9271 - 6149.1/(t^{\circ}\text{C} + 273.15)$$

and for heavy water in the range 3.8 to -60°C by:

$$\log e P(\text{Pascal}) = 29.608 - 6402.2/(t^{\circ}\text{C} + 273.15)$$

Such corrections do not normally apply to the EG&G instrument since it senses condensation and dew point directly; care has to be taken, however, that the same form of water is on the mirror and in the vapor being measured. For example, if light water is present on the mirror and the surrounding gas contains only heavy water, the EG&G will read about 3°C low at first with the reading increasing until all the light water on the mirror is replaced by heavy water.

V.P.Singh, Laboratory Tests on the Performance of Aluminum Oxide, Silicon and Optical Chilled Mirror Hygrometers, OHRD Report 88-207-H, (1988).

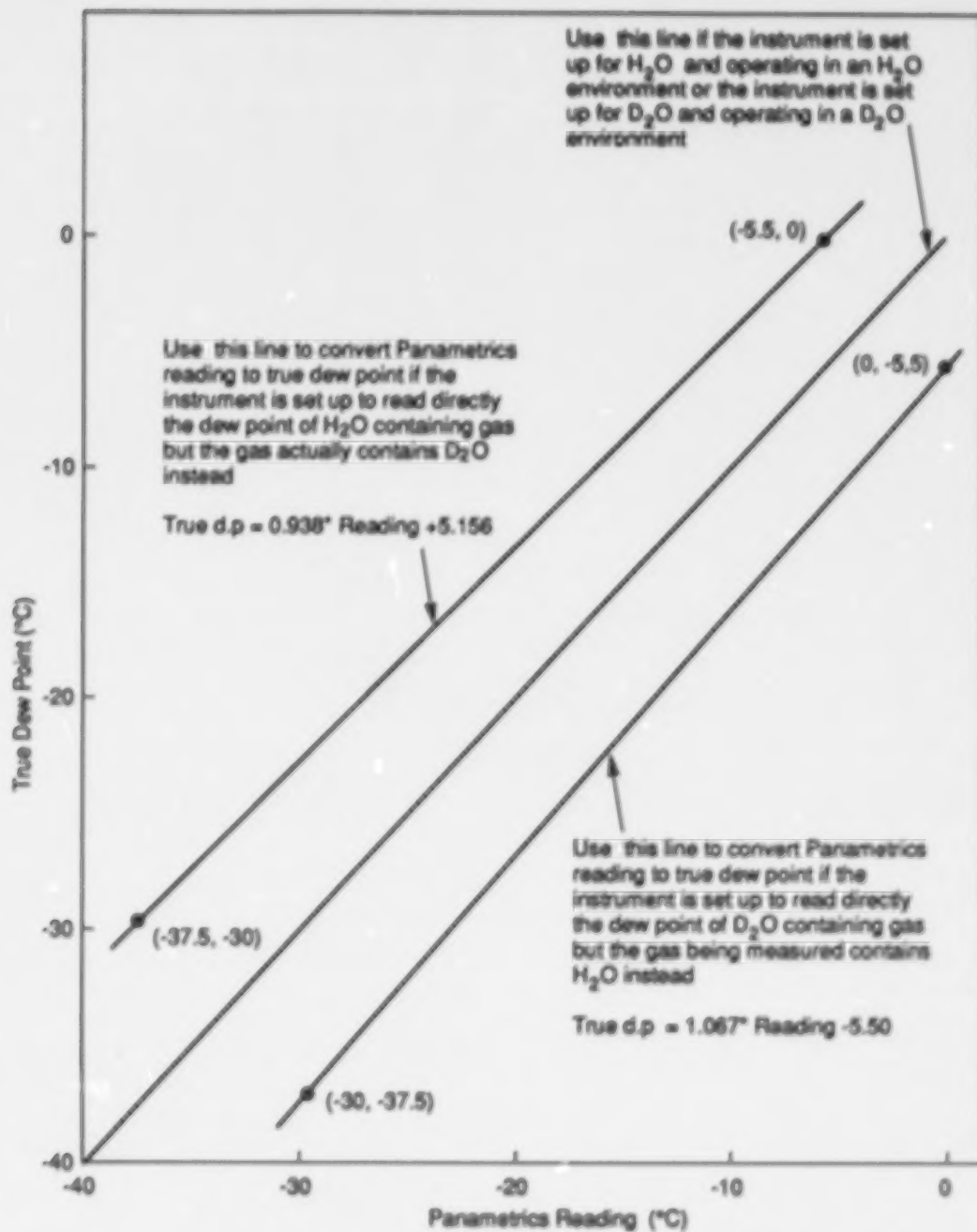


FIGURE B.1

CONVERSION OF PANAMETRICS READING FOR DIFFERENT
CALIBRATION AND OPERATING CONDITIONS

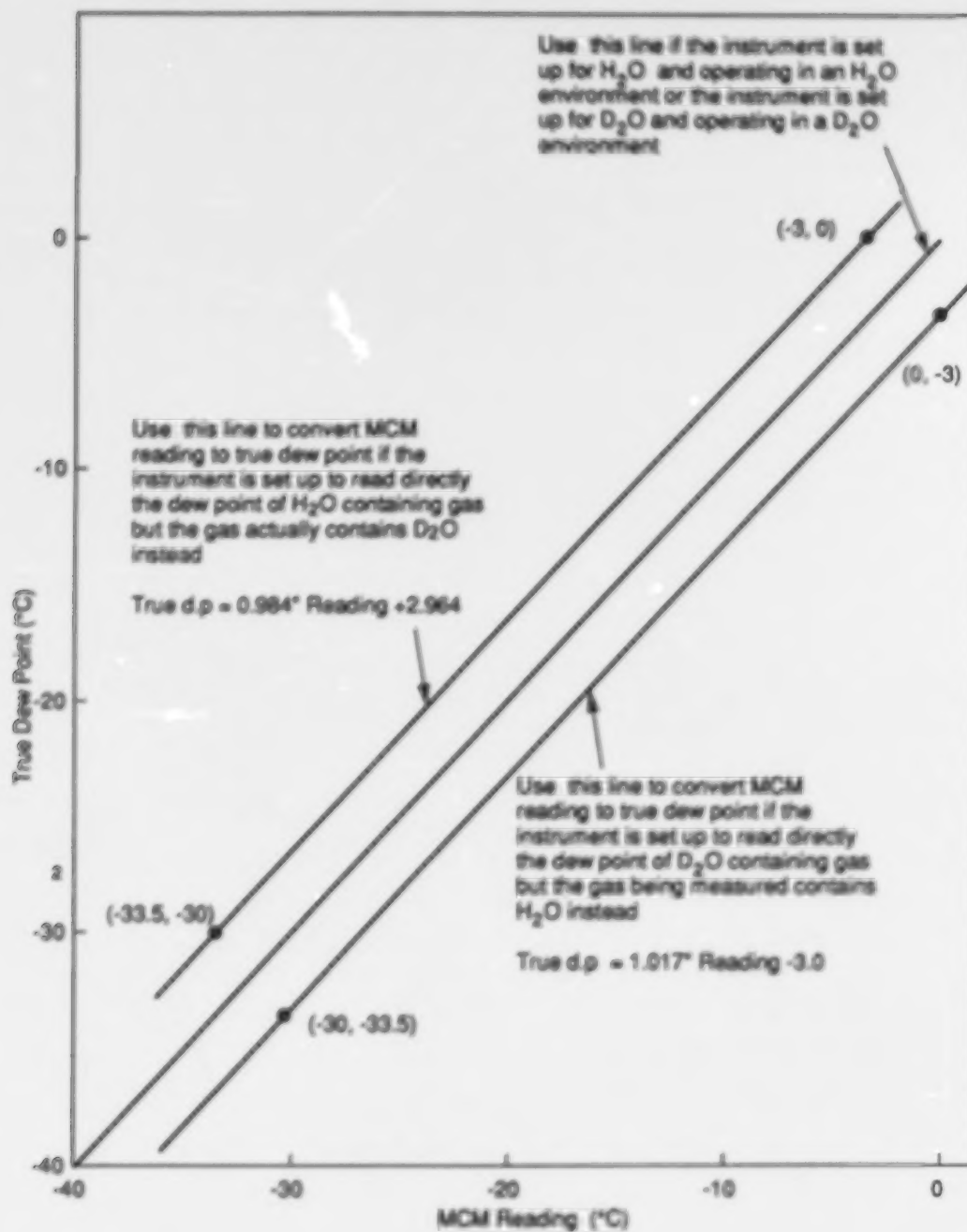


FIGURE B.2
CONVERSION OF MCM READING FOR DIFFERENT
CALIBRATION AND OPERATING CONDITIONS

APPENDIX C

TEMPERATURE, PRESSURE AND FLOW DATA

Room temperature and raw data for the overall system flow rate as well as the individual string rotameters are given in Table C.1.

The OHRD dew point sample train pressure which is close to the pressure at the in-station moisture elements are given as a function of time in Table C.2.

From Table C.3, the total flow rate given by FI50 divided into 48 strings is about 14% lower than the value found by calibration (Figure C.1) of a typical string rotameter.

Pressure drop data are shown in Table C.4. In general, the pressures at the inlets of the longer strings were higher than for the shorter strings but not proportional to string length because of the pressure drops over the inlet tubings and the filter at the calandria exit. It appears that about 30 to 40 kPa of pressure is being throttled between the compressor exit and the exit of the rotameters. It is recommended that an investigation be carried out aimed at reducing the throttling to possibly increase metal bellows pump life.

Data on Darlington Rotameter on Strings

Brooks Serial No: 8302H09657/7

Model No: 1355CB1C1B2213

Scale Indication R 30 50 100 150 200 250 300 350 400

| mL/sec Gas Sp Gr 2.41@40°C&82kPa(g),11.5psig

Read middle of ball

Needle valve on exit = 6 or 9

Valve fitting = A423

Rotameter End Blocks = A422

Inlet Fitting = A426

Brooks Tube = 9-84; Tube Size R-6-15B

Do not exceed 200psig at 250°C

Springs used as ball stops, inlet and outlet.

Tag on Rotameter = 63488-FI37

SCN 611J7760

TABLE C.1. ROOM TEMPERATURE, TOTAL FLOW RATE AND STRING FLOW RATES (RAW DATA).

TEST NUMBER	TOTAL* (% FULL SCALE)	STRING FLOW RATES			TEMP R2-121 (C)
		250 STRING ROTAMETER READINGS	1100 1100	1200 1200	
1	70	-	-	-	
2	68-69**	107	105	60	
3	70-72	55	105	105	
4	71 TO 73	105 TO 110	55	102 TO 112	26 31(R2-002)
5	68 TO 72	106	102	55	
6	65-68	-	-	-	29(R2-002)
8	65-68	50	100	100	24
9	39 TO 41	33 TO 35	65 TO 90	66 TO 90	25
10	66-68	102 TO 105	59 TO 59	100 TO 103	26
13	65-67	100 TO 100	100 TO 100	90 TO 92	25
14	39.5 TO 41	71 TO 74	68 TO 68	33 TO 33	26
15	57	95	94	47	22

* CALIBRATION CONDITIONS: SPECIFIC GRAVITY 1.516(CO₂); 32 DEG C; 104.3 kPa(a)
 FULL SCALE = 6.3 L/s GAS AT CALIBRATION CONDITIONS & 6.34 L/s GAS AT 25 DEG C, 101.3kPa(a)

** READING CYCLING BETWEEN LIMITS

TABLE C.2 DEW POINT SAMPLE TRAIN PRESSURE AS A FUNCTION OF TIME

TEST NUMBER	PRESSURE	TIME DEPENDENCE			CO ₂ DETECTION RATE (L/MIN) (25C, 101kPa)
		250 PRESSURE(KILOPASCAL)=	1100 TIME(MIN)=	1200 TIME(MIN)=	
1	PRESSURE(KILOPASCAL)=	23.38	+	0.0339	6.0 3.1 3.1
	PRESSURE(KILOPASCAL)=	23.28	+	0.0339	
	PRESSURE(KILOPASCAL)=	20.15	+	0.0278	
6	PRESSURE(KILOPASCAL)=	21.04	+	0.0752	5.97
10	PRESSURE(KILOPASCAL)=	25.01	+	0.0306	3.13 3.13 3.13
	PRESSURE(KILOPASCAL)=	25.01	+	0.0306	
	PRESSURE(KILOPASCAL)=	25.01	+	0.0306	
13	PRESSURE(KILOPASCAL)=	20.21	+	0.0306	3.13 3.13 3.13
	PRESSURE(KILOPASCAL)=	22.21	+	0.0306	
	PRESSURE(KILOPASCAL)=	22.21	+	0.0306	

TABLE C.3 TOTAL FLOW RATE AND STRING FLOW RATES.

TEST NUMBER	TOTAL FLOW RATE (L/MIN; 25°C; 101 kPa)	STRING FLOW RATES** (L/MIN; 25°C; 101 kPa)	INLET PRESSURE (PSI)	CO2 INJECTION RATE (L/MIN; 25°C; 101 kPa)	TEST FLOW RATE (L/MIN; 25°C; 101 kPa)
1	291 TO 303	-	-	6.0	-
2	274 TO 278	6.75	6.7	3.7	7.55
3	295 TO 308	3.6 TO 3.8	6.7 TO 7.0	3.8	7.5
4	303 TO 325	7.0 TO 7.6	3.8 TO 4.0	3.8	7.7
5	283 TO 314	6.95 TO 7.2	6.7 TO 6.95	3.8	7.55
6	274 TO 286	-	-	5.97	-
8	278 TO 284	3.35 TO 3.45	6.6 TO 6.7	3.13	6.53
9	164 TO 178	1.9 TO 2.15	3.8 TO 4.35	2.00	4.03
10	277 TO 293	6.7 TO 7.1	3.35 TO 3.5	3.13	6.55
13	272 TO 280	6.55 TO 7.05	6.55 TO 7.05	3.13	6.58
14	168 TO 179	4.3 TO 4.6	4.1 TO 4.35	2.00	4.05
15	259	6.4	6.3	3.13	6.38

* L/MIN AT ROTAMETER CALIBRATION CONDITIONS = X READING $\times$ CORRECTION FACTOR;
CORRECTION FACTOR = $(P_o/P_c)^{1/2}$; P_o = OPERATING PRESS; P_c = CALIBRATION TEMP.;
THEN CONVERT TO L/MIN AT 25°C AND 101.3 kPa(a)

NOTE THAT THE MASS FLOW RATE OF GAS INCREASES WITH TIME AS PRESSURE INCREASES
BUT THE VOLUMETRIC FLOW RATE (L/MIN AT THE EXISTING PRESSURE) IS NEARLY CONSTANT.

** ASSUMES 5 kPa PRESSURE DROP BETWEEN COMPRESSOR OUTLET AND STRING ROTAMETERS
FOR 2 COMPRESSOR OPERATION AND 3 kPa FOR 1 CP OPERATION

Δ TOTAL FLOW OF 273 L/MIN DIVIDED INTO 48 STRINGS GIVES AN AVERAGE OF 5.7 L/MIN/STRING;
THIS IS LOW COMPARED TO THE INDIVIDUAL STRING RATES OF 6.6 L/MIN.

*** STRING UNDER TEST; TOTAL STRING FLOW RATE = INJECTION RATE + STRING FLOW RATE

TABLE C-4. SYSTEM PRESSURES, TOTAL FLOW RATE AND STRING FLOW RATES.

TEST NUMBER	TOTAL* FLOW RATE (25C, 101kPa)	CHANNELS IN TEST STRING	TEST STRING FLOW RATE (L/MIN) (25C, 101kPa)	SYSTEM PRESSURE AT COMPRESSOR EXIT (P70) (kPa(g))	PRESSURE AT INJECTION POINT (kPa(g))	D.P. SAMPLE MAIN PRESSURE (kPa(g))	PRESSURE DROP OVER TEST STRING (kPa(g))
1	291 TO 303	EXT	-	97.5	73.5 TO 95.5	22.5 TO 32.5	51 OVERALL
2	274 TO 278	12	7.55	78.5	34.5	15	17.5
3	295 TO 308	4	7.5	82 TO 99	36 TO 48	22 TO 33.5	12 TO 12.5
4	303 TO 325	11	7.7	93 TO 113 (EST)	51 TO 62	29 TO 41	20 TO 19
5	283 TO 314	12	7.55	84 TO 102	44 TO 55	22.5 TO 34.5	19.5 TO 18.5
6	274 TO 286	EXT	-	85 TO 97	84 TO 95	20.5 TO 31	61 TO 62 OVERALL
8	278 TO 284	4	6.53	88 TO 97	36 TO 44.5	24 TO 29.5	10 TO 13
9	164 TO 178	4	4.03	58 TO 67	33.5 TO 41	26 TO 34	6.5 TO 6
10	277 TO 293	11	6.55	86 TO 100	46 TO 53	25 TO 32.5	19 TO 18.5
13	272 TO 280	12	6.58	85 TO 97	44 TO 53	20.5 TO 27.5	21.5 TO 23.5
14	168 TO 179	12	4.05	60 TO 68	40.5 TO 48	28 TO 35	11.5 TO 12
15	259	12	6.38	99	66.5	47.5	17

* PRESSURE INCREASING OVER TEST PERIOD

** PRESSURE AT F150 SIMILAR TO SAMPLE TRAIN PRESSURE

*** ASSUMES 2 kPa PRESSURE DROP OVER FILTER FOR 2CP OPERATION AND 1 kPa PRESSURE DROP OVER FILTER FOR 1 CP OPERATION

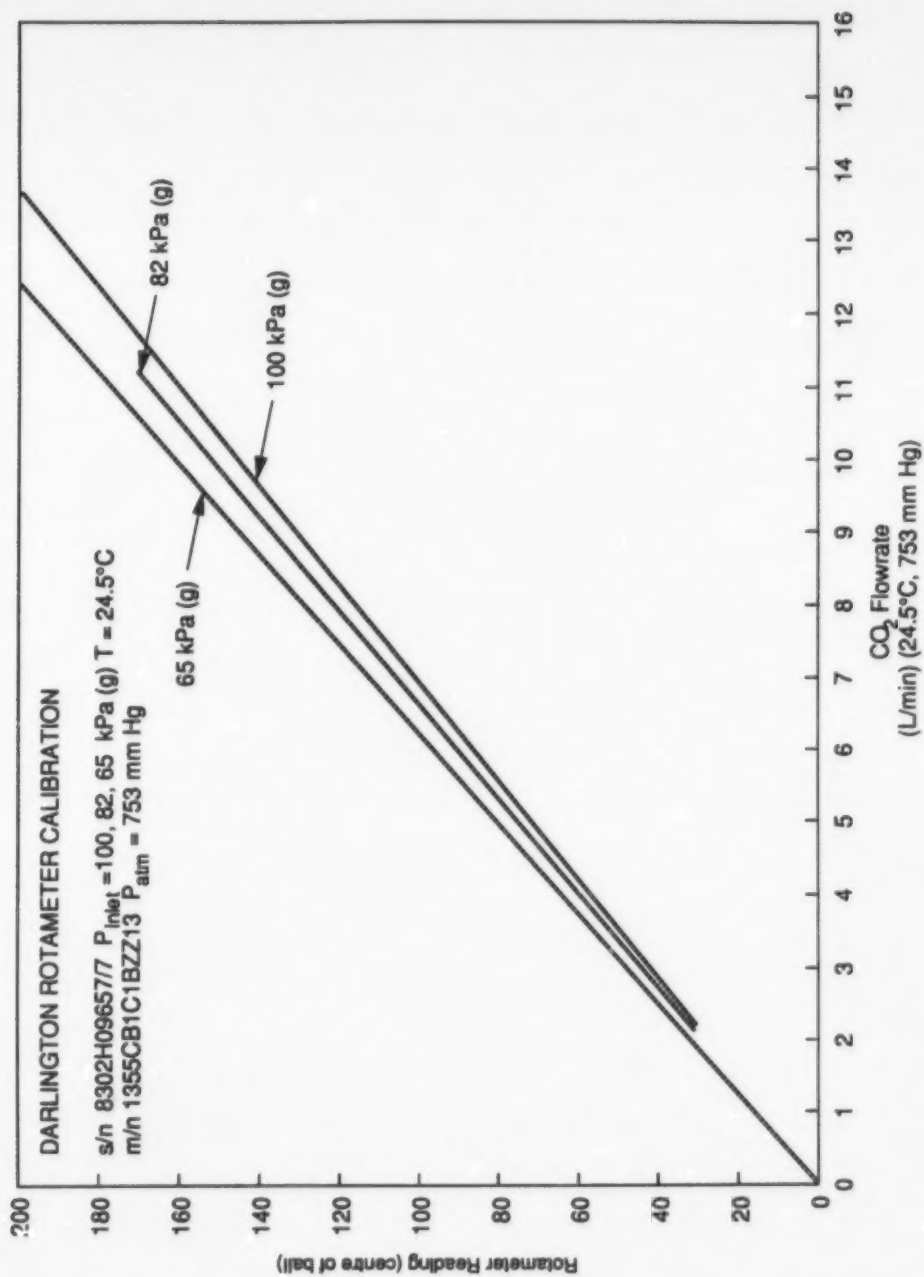


FIGURE C-1
STRING ROTAMETER CALIBRATION (TYPICAL)

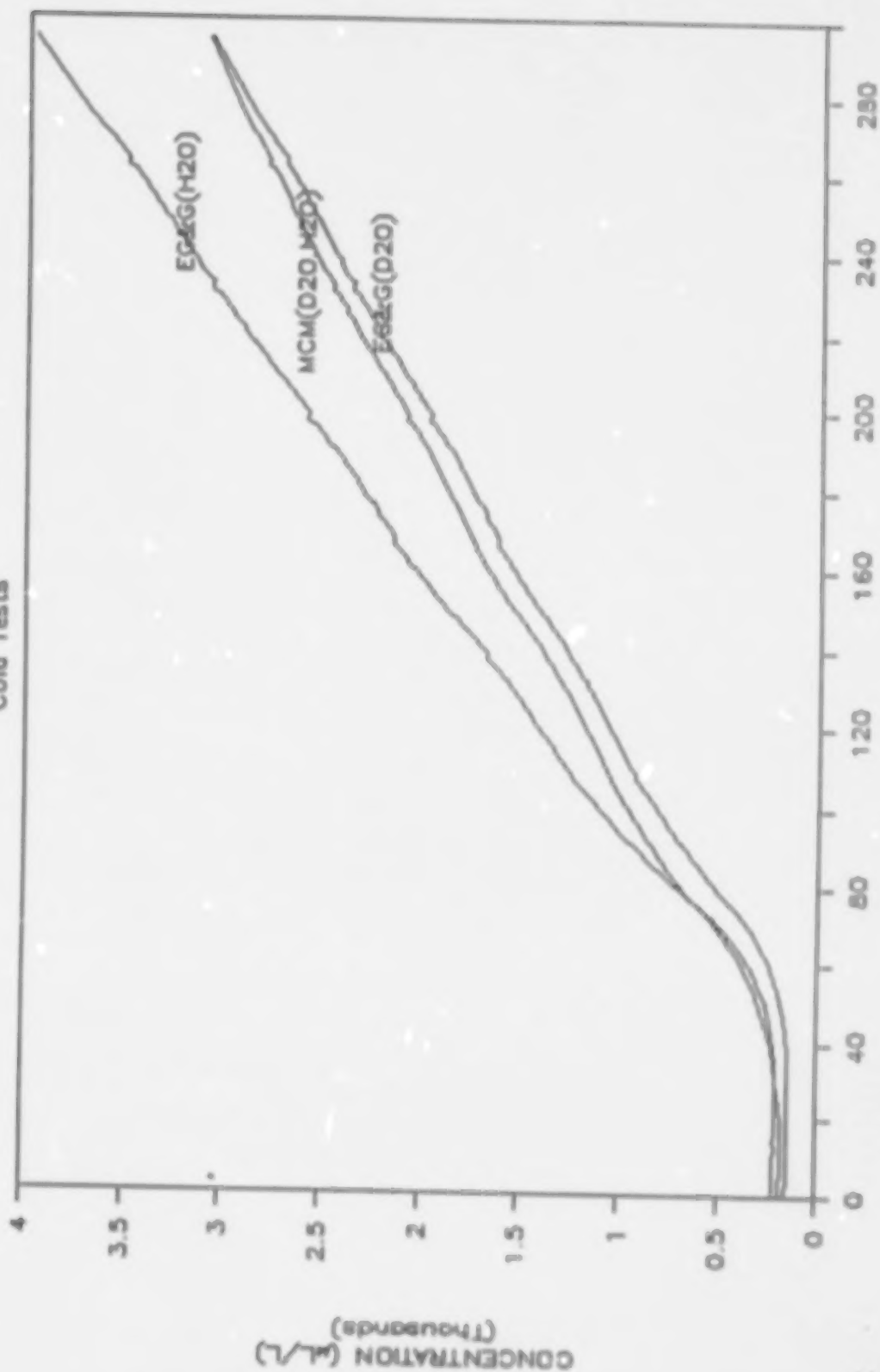
APPENDIX D

CONCENTRATION DATA

Dew point readings from Appendix A were converted to true dew point assuming a particular isotope was present as described in Appendix B. Then concentrations were determined from the vapor pressure vs temperature relationships for the particular isotope assumed present and the system pressure at the relevant time. These data are given in the following graphs (tests 7, 11 and 12 deleted). Note that corrections to these concentration vs time graphs have not been made for concentration increase due to background moisture from desorption, etc and for the carbon dioxide carrier which causes a pressure increase.

DARLINGTON AGS TEST 1

Cold Tests



ELAPSED TIME (min)

FIGURE D-1(a)

CONCENTRATION VS TIME FOR TEST 1 (MCM AND EG&G)

DARLINGTON AGS TEST 1

Cold Tests

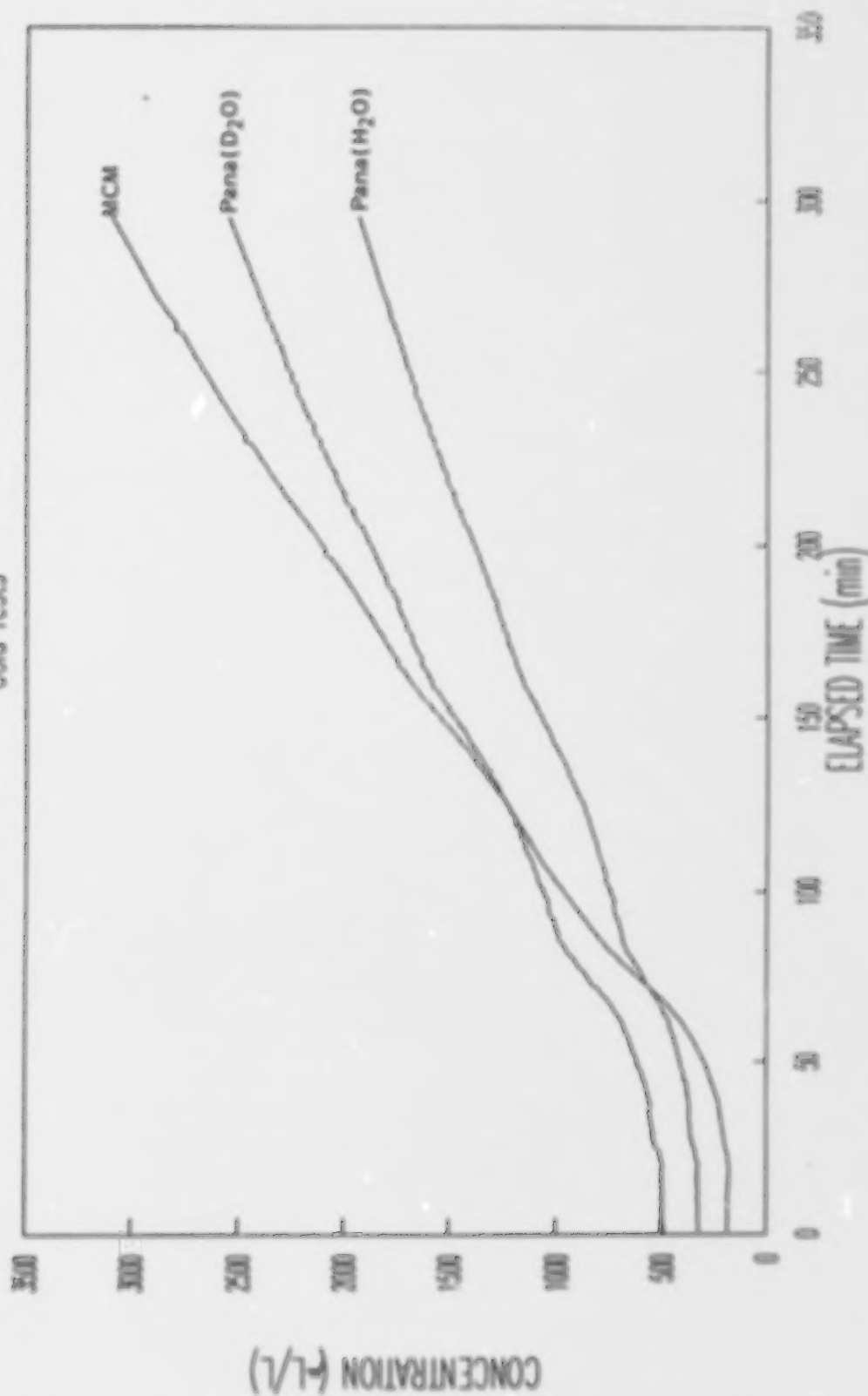


FIGURE D-1(b)

CONCENTRATION VS. TIME FOR TEST 1 (MCM AND PANAMETRICS)

DARLINGTON AGS TEST 2

Cold Tests

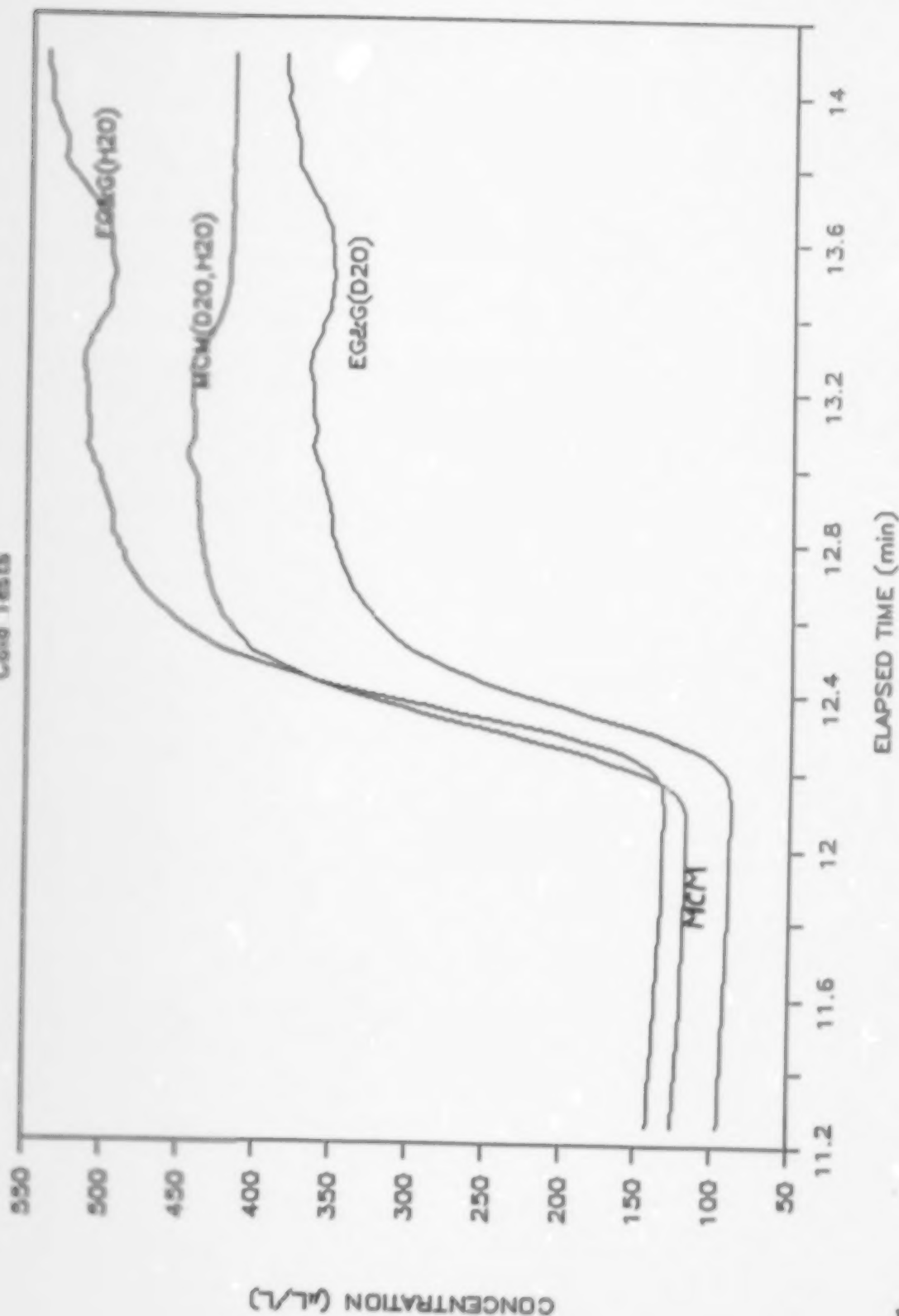


FIGURE D-2(a)

CONCENTRATION VS TIME FOR TEST 2 (MCM AND EG&G)

DARLINGTON AGS TEST 2

Cold Tests



ELAPSED TIME (min)

FIGURE D-2(b)

CONCENTRATION VS TIME FOR TEST 2 (MCM AND PANAMETRICS)

184360-RD

90-298

DARLINGTON AGS TEST 3

Cold Tests



ELAPSED TIME (min)

FIGURE D-3(a)

CONCENTRATION VS TIME FOR TEST 3 (MCM AND EG&G)

DARLINGTON AGS TEST 3

Cold Tests

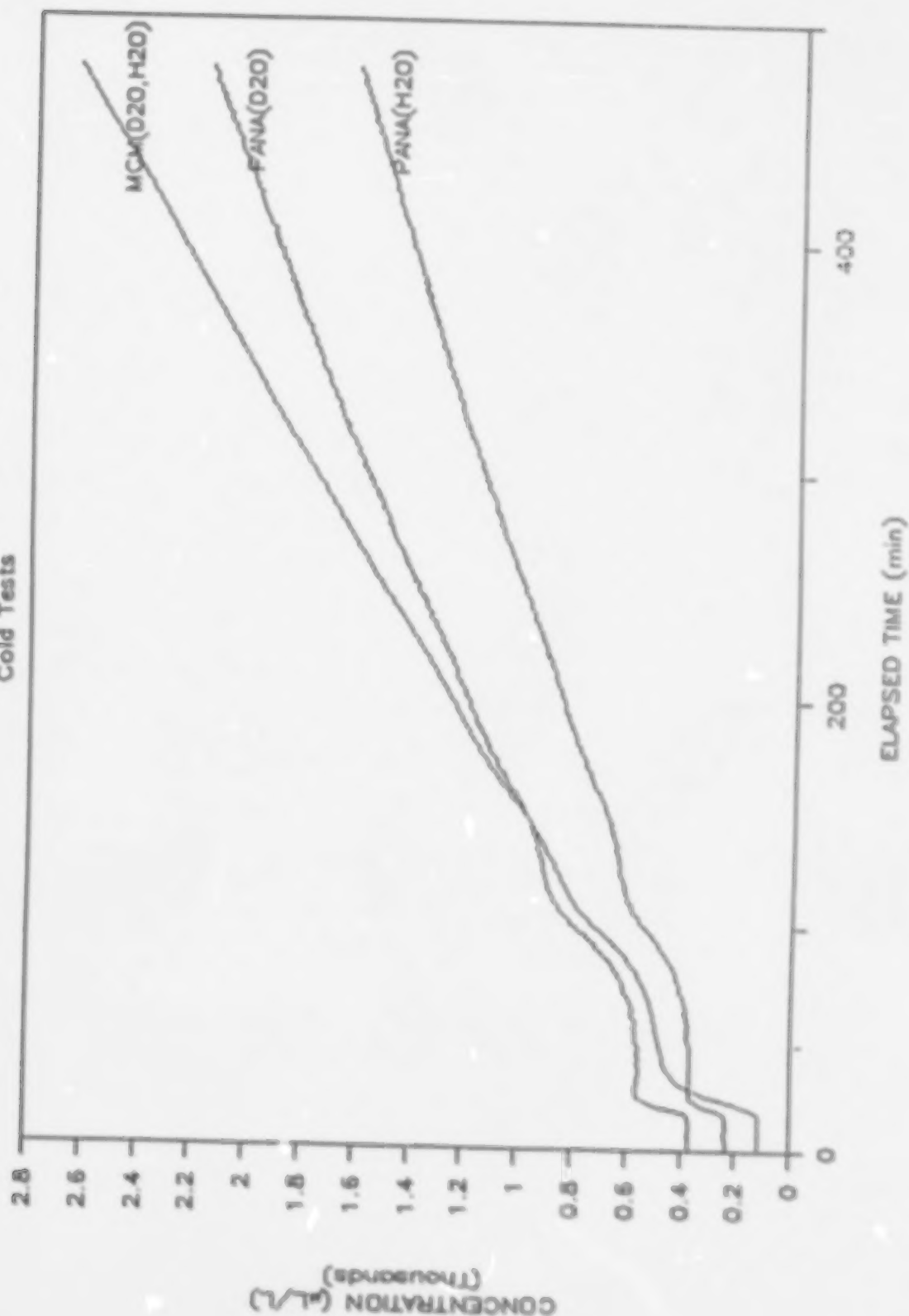


FIGURE D-3(b)
CONCENTRATION VS TIME FOR TEST 3 (MCM AND PANAMETRICS)

DARLINGTON AGS TEST 4

Cold Tests

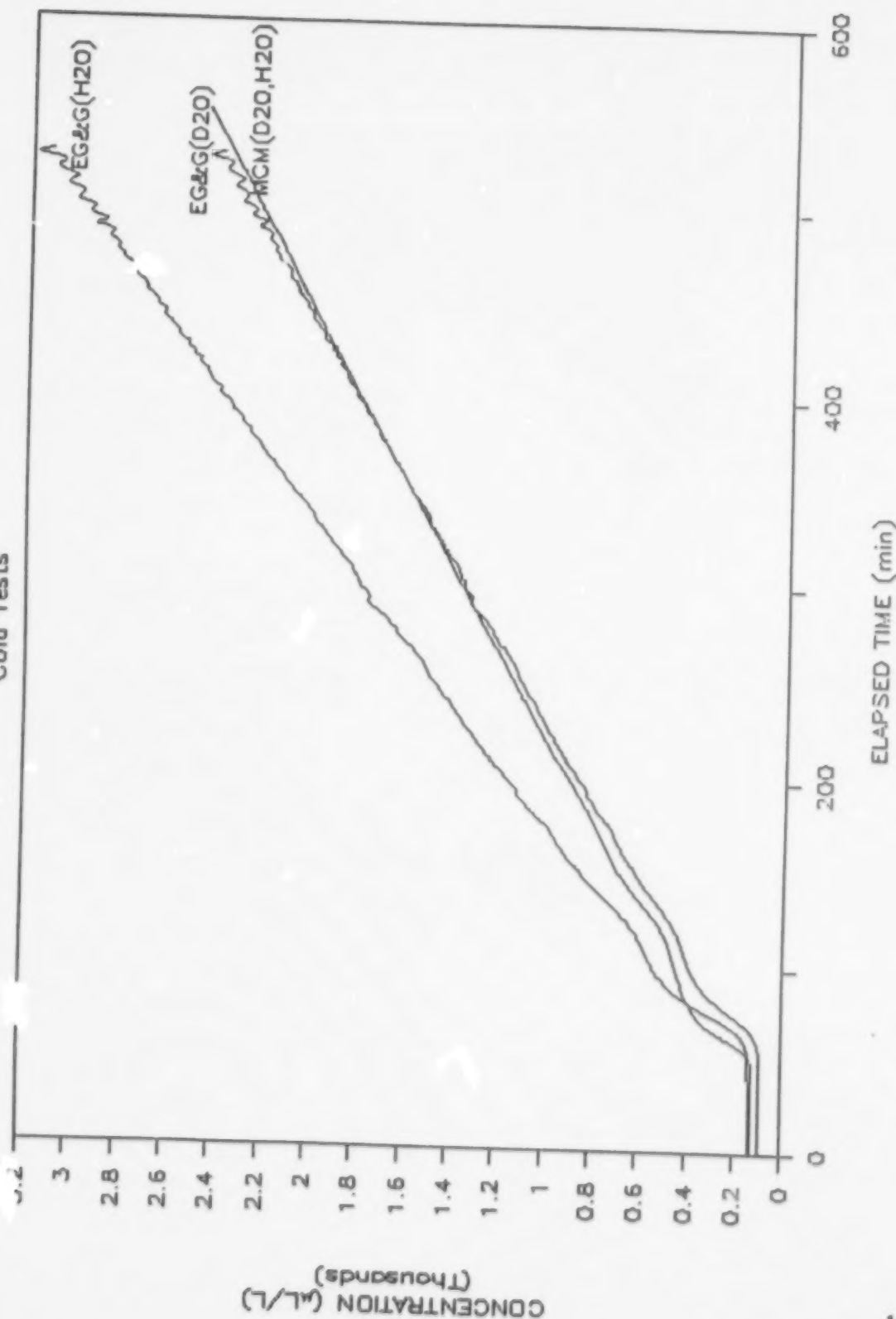


FIGURE D-4(a)

CONCENTRATION VS TIME FOR TEST 4 (MCM AND EG&G)

184363-RD

90-298

D8

DARLINGTON AGS TEST 4

Cold Tests



ELAPSED TIME (min)

FIGURE D-4(b)

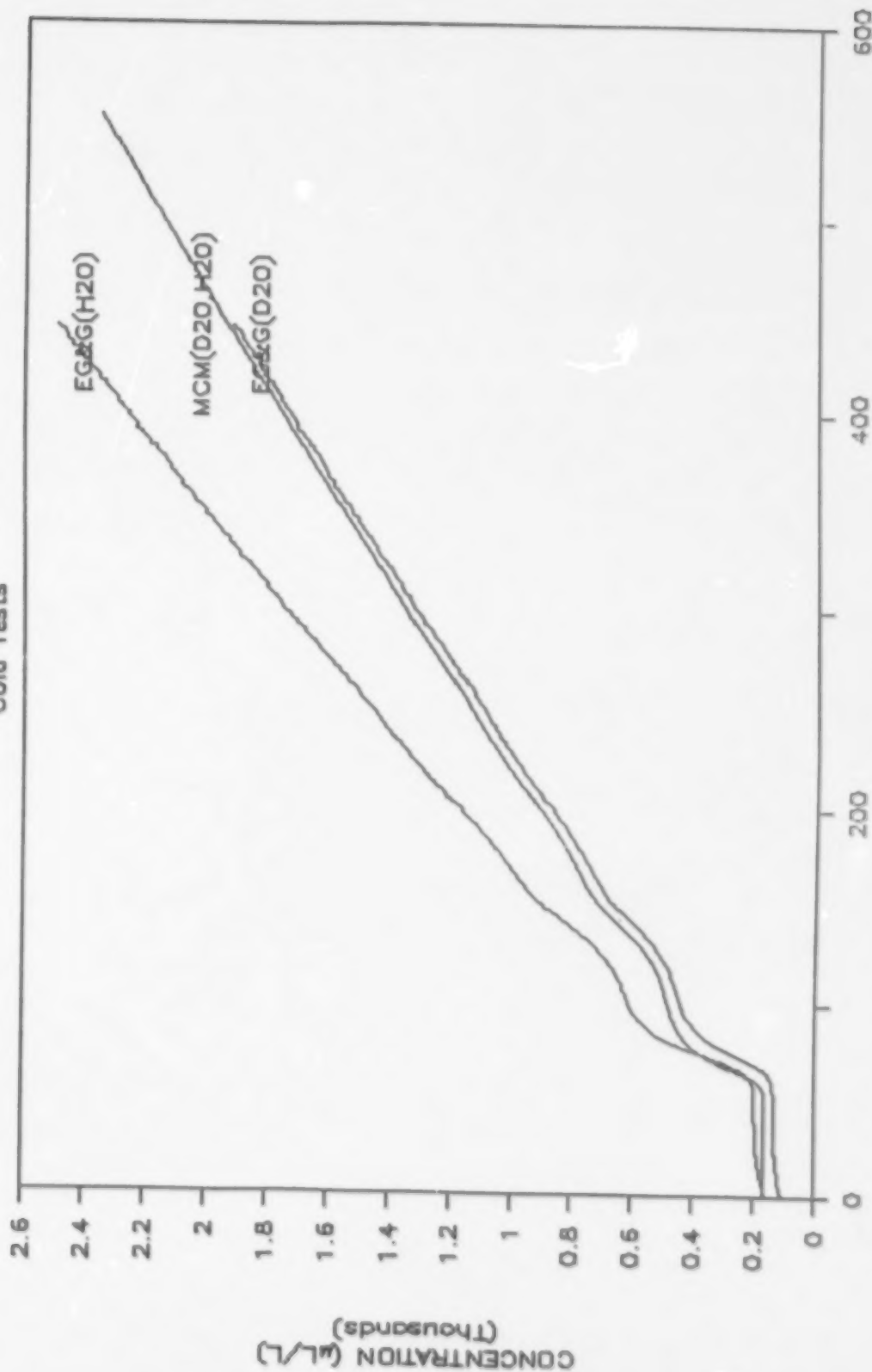
CONCENTRATION VS TIME FOR TEST 4 (MCM AND PANAMETRICS)

184364-RD

90-298

DARLINGTON AGS TEST 5

Cold Tests



ELAPSED TIME (min)

FIGURE D-5(a)

CONCENTRATION VS TIME FOR TEST 5 (MCM AND EG&G)

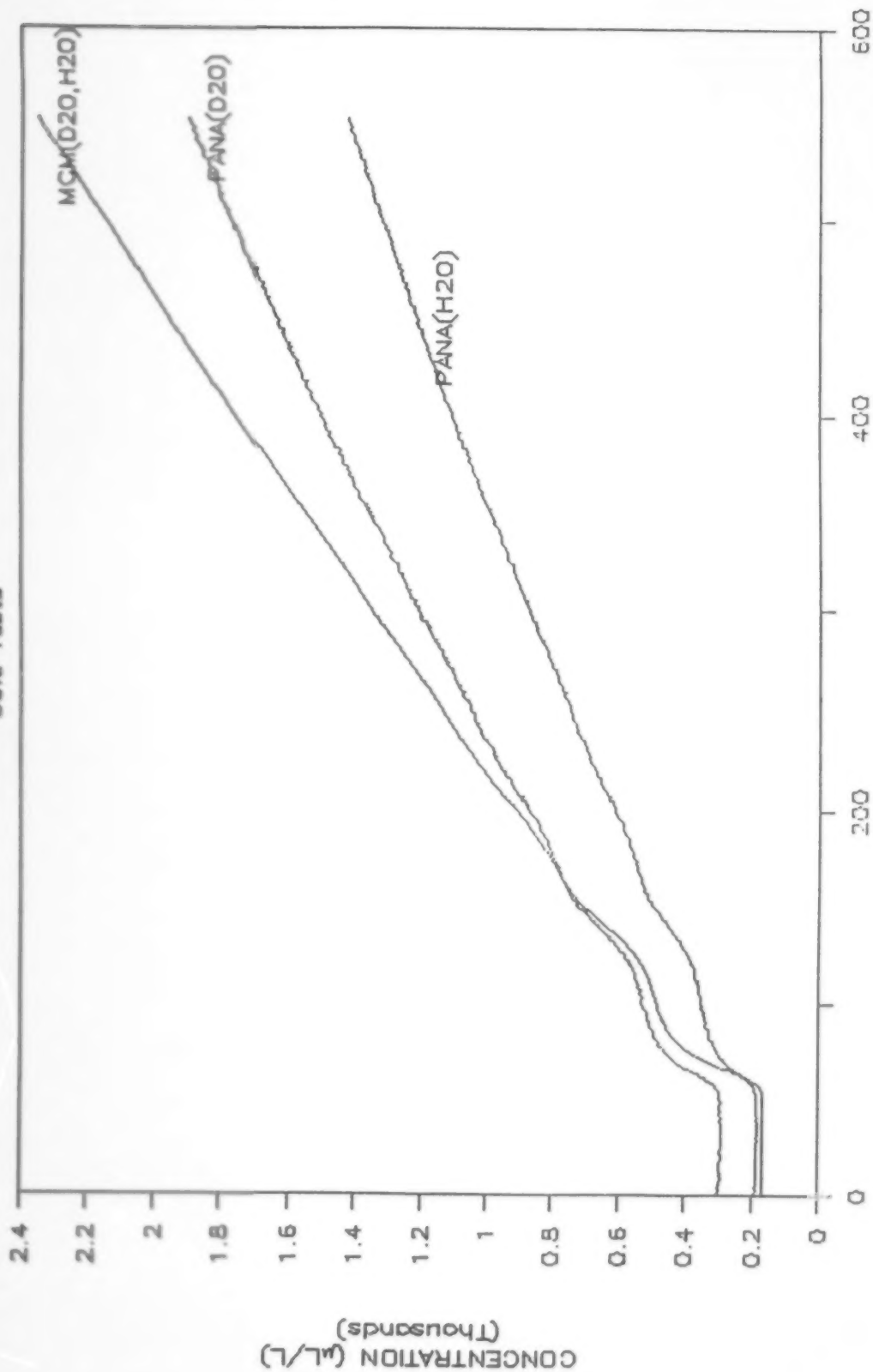
184365-RD

90-298

D10

DARLINGTON AGS TEST 5

Cold Tests



ELAPSED TIME (min)

FIGURE D-5(b)

CONCENTRATION VS TIME FOR TEST 5 (MCM AND PANAMETRICS)

184366-RD

90-298

D11

DARLINGTON AGS TEST 6

MCM Concentration Partially Corrected

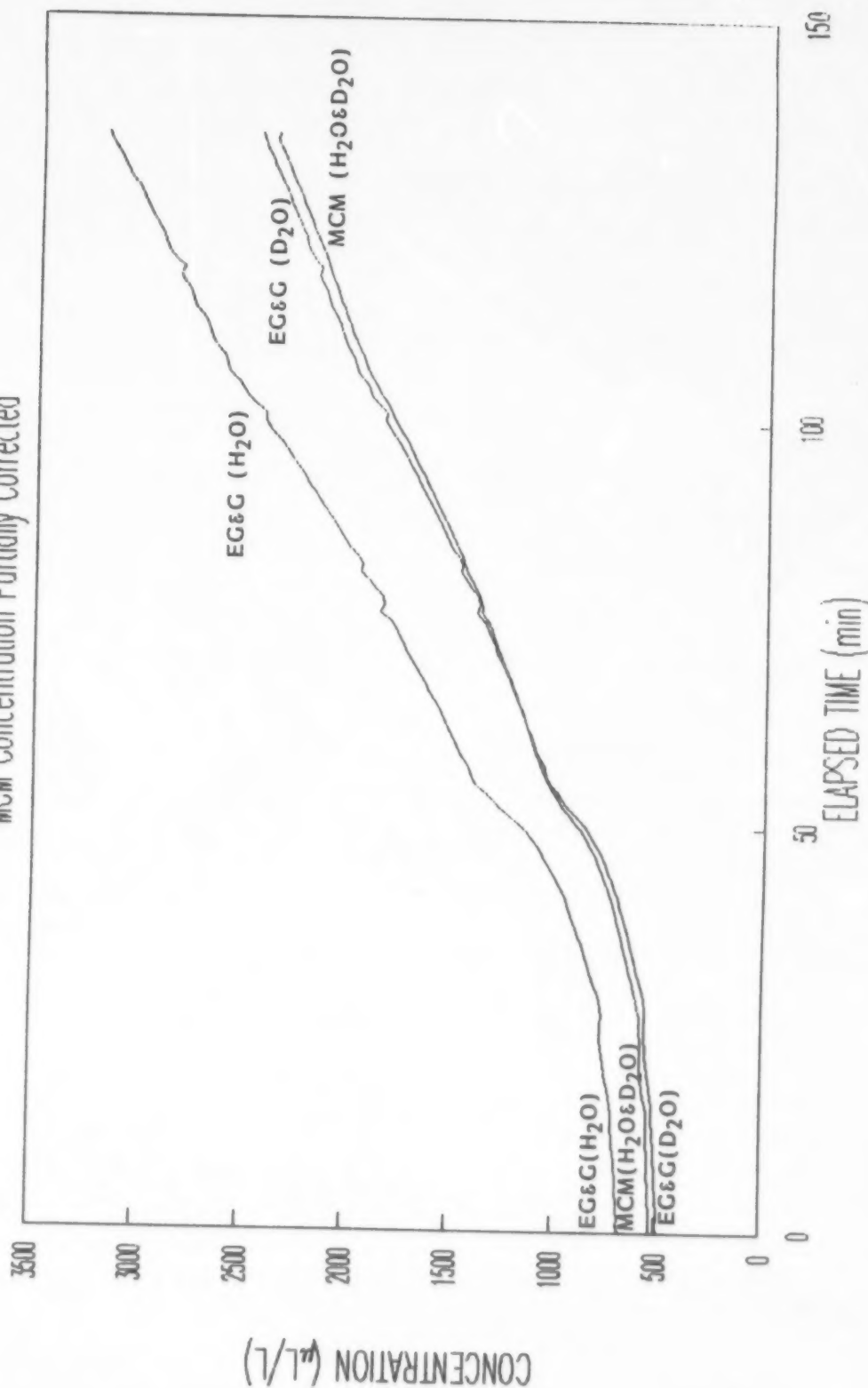


FIGURE D-6(a)

CONCENTRATION VS TIME FOR TEST 6 (MCM AND EG&G)

DARLINGTON AGS TEST 6

MCM Concentration Partially Corrected

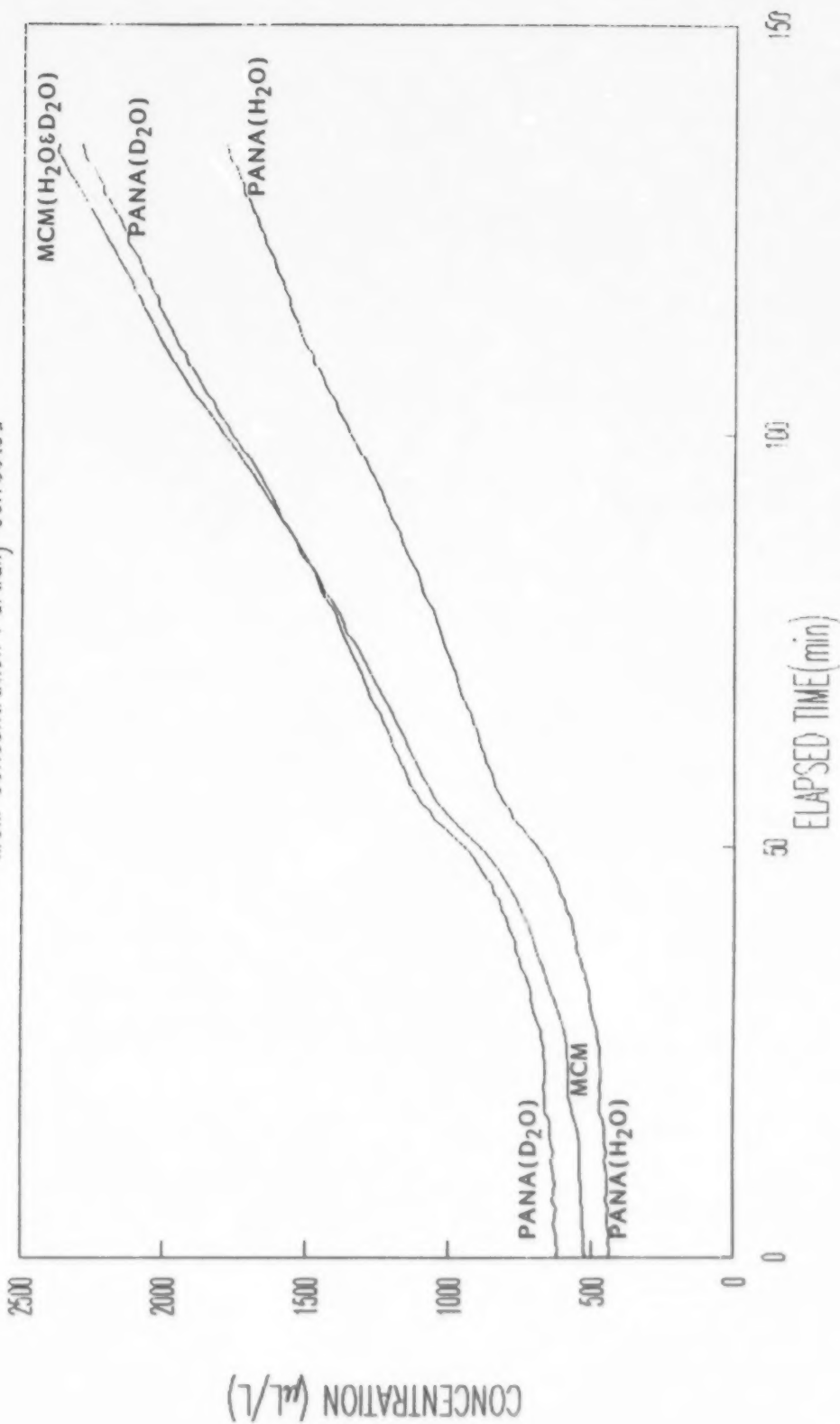


FIGURE D-6(b)
CONCENTRATION VS TIME FOR TEST 6 (MCM AND PANAMETRICS)

DARLINGTON AGS TEST 6

MCM Concentration Partially Corrected

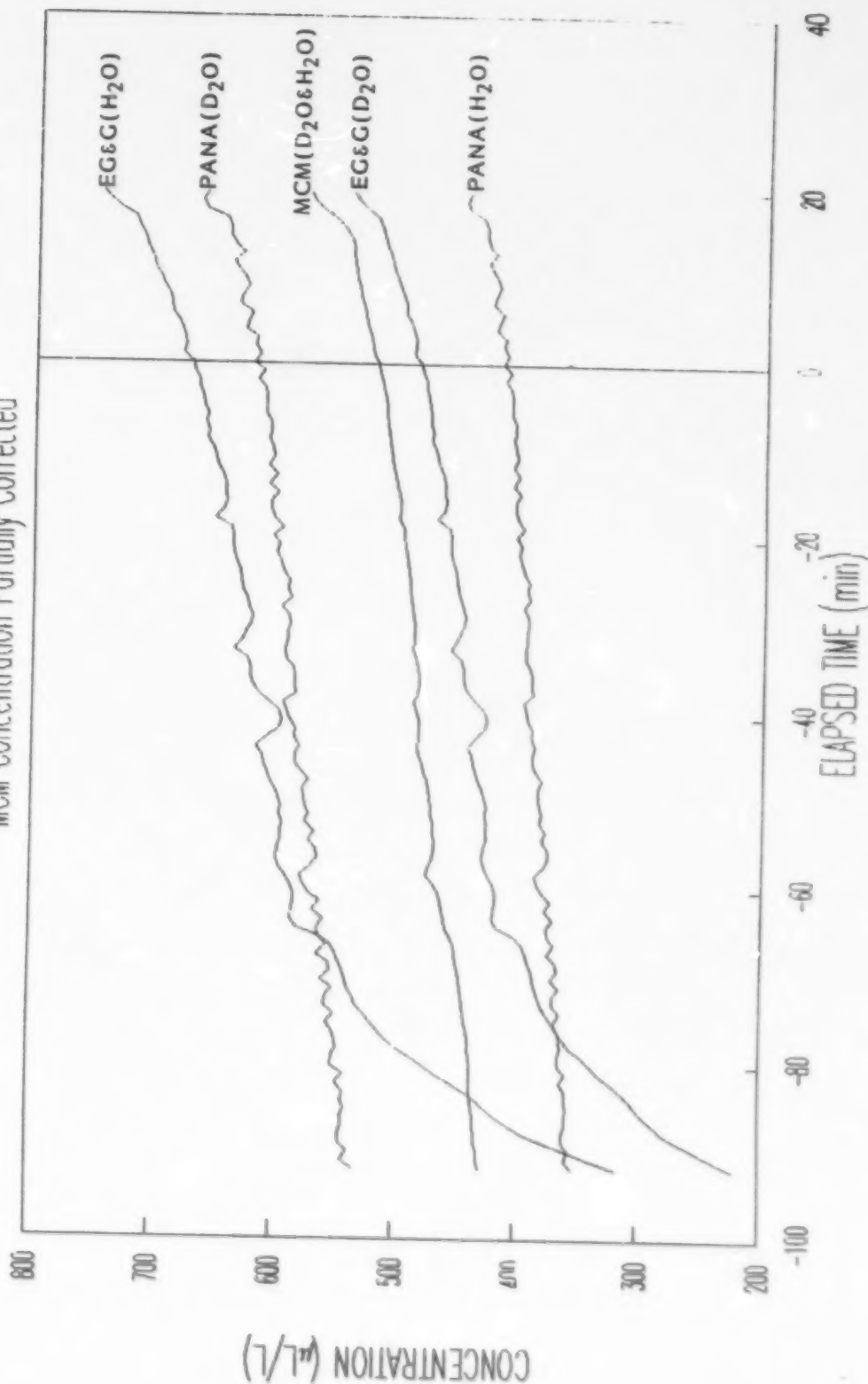


FIGURE D-6(c)
CONCENTRATION VS TIME FOR TEST 6 (PRE-INJECTION)

DARLINGTON AGS TEST 8

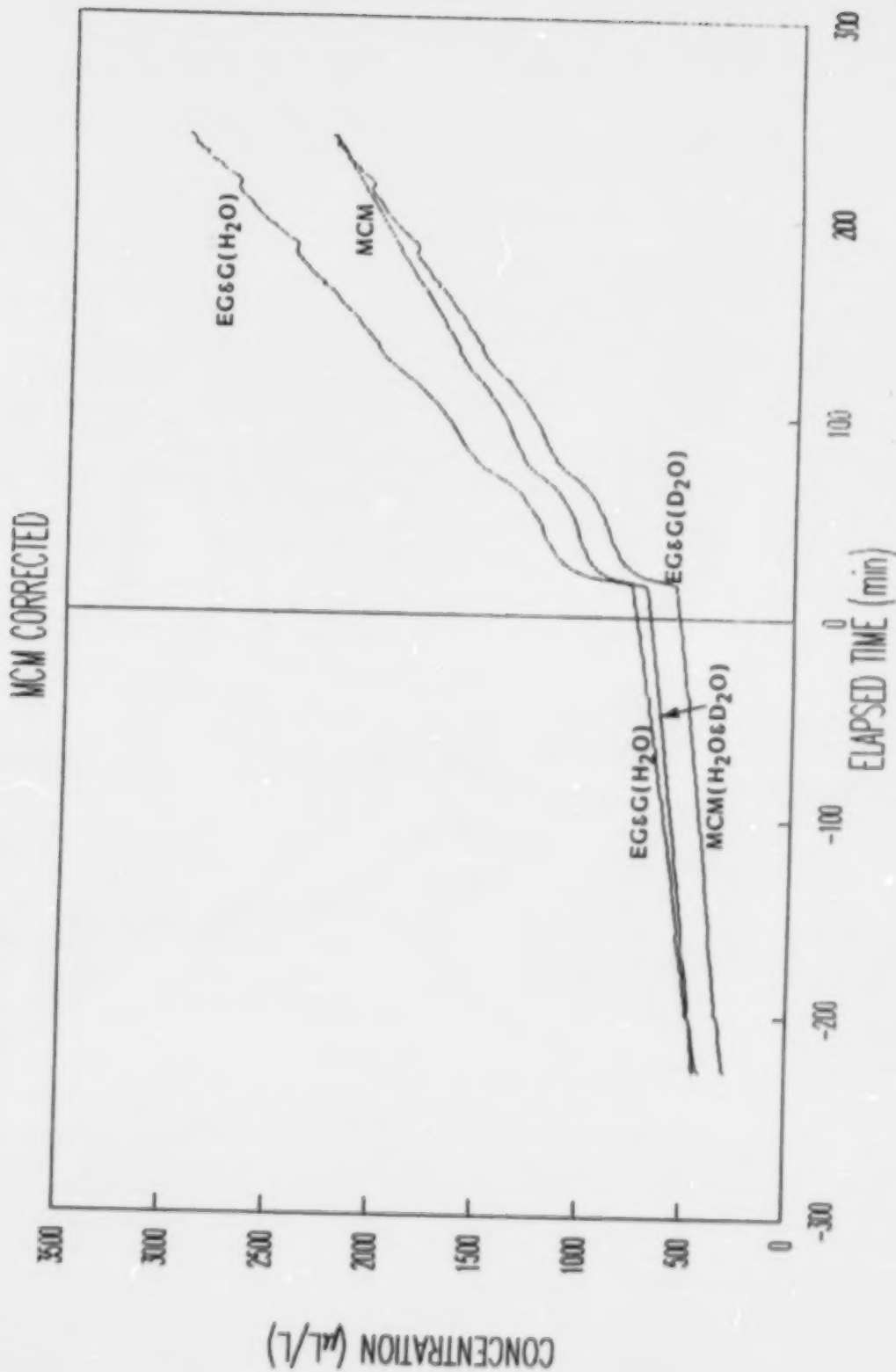


FIGURE D-8(a)
CONCENTRATION VS TIME FOR TEST 8 (MCM AND EG&G)

DARLINGTON AGS TEST 8

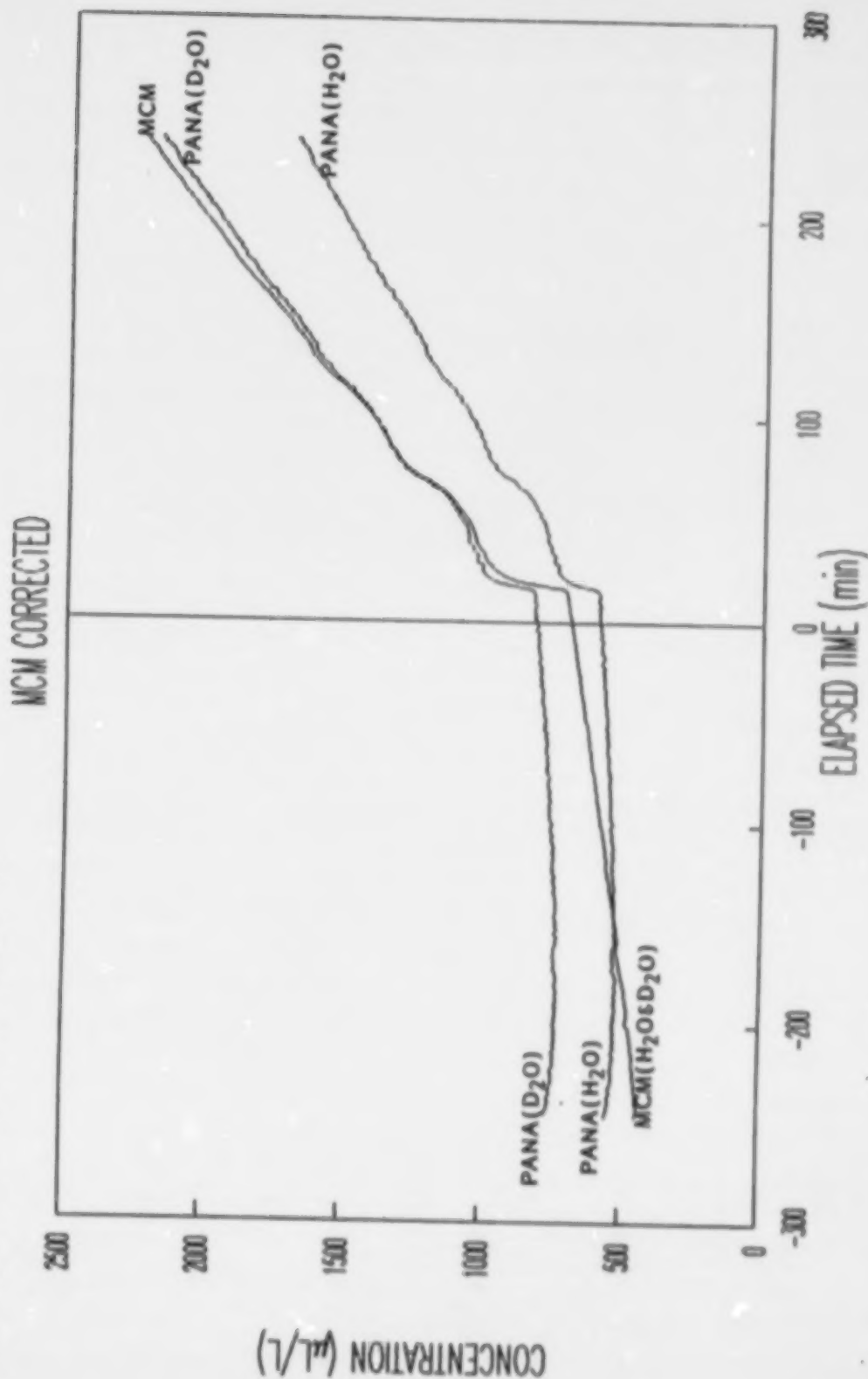


FIGURE D-8(b)
CONCENTRATION VS TIME FOR TEST 8 (MCM AND PANAMETRICS)

DARLINGTON AGS TEST 9

MCM CORRECTED

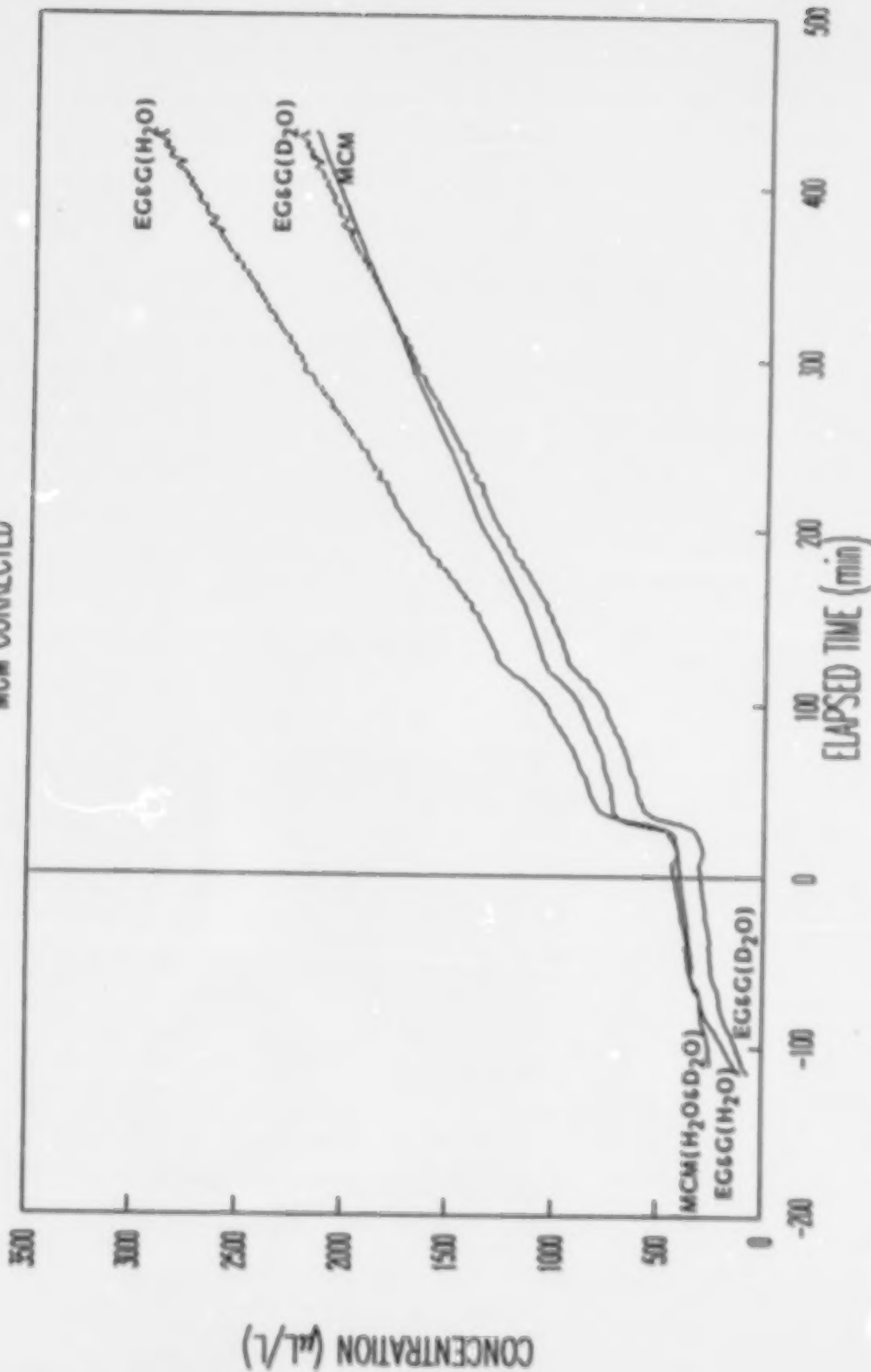


FIGURE D-9(a)

CONCENTRATION VS TIME FOR TEST 9 (MCM AND EGSG)

DARLINGTON AGS TEST 9

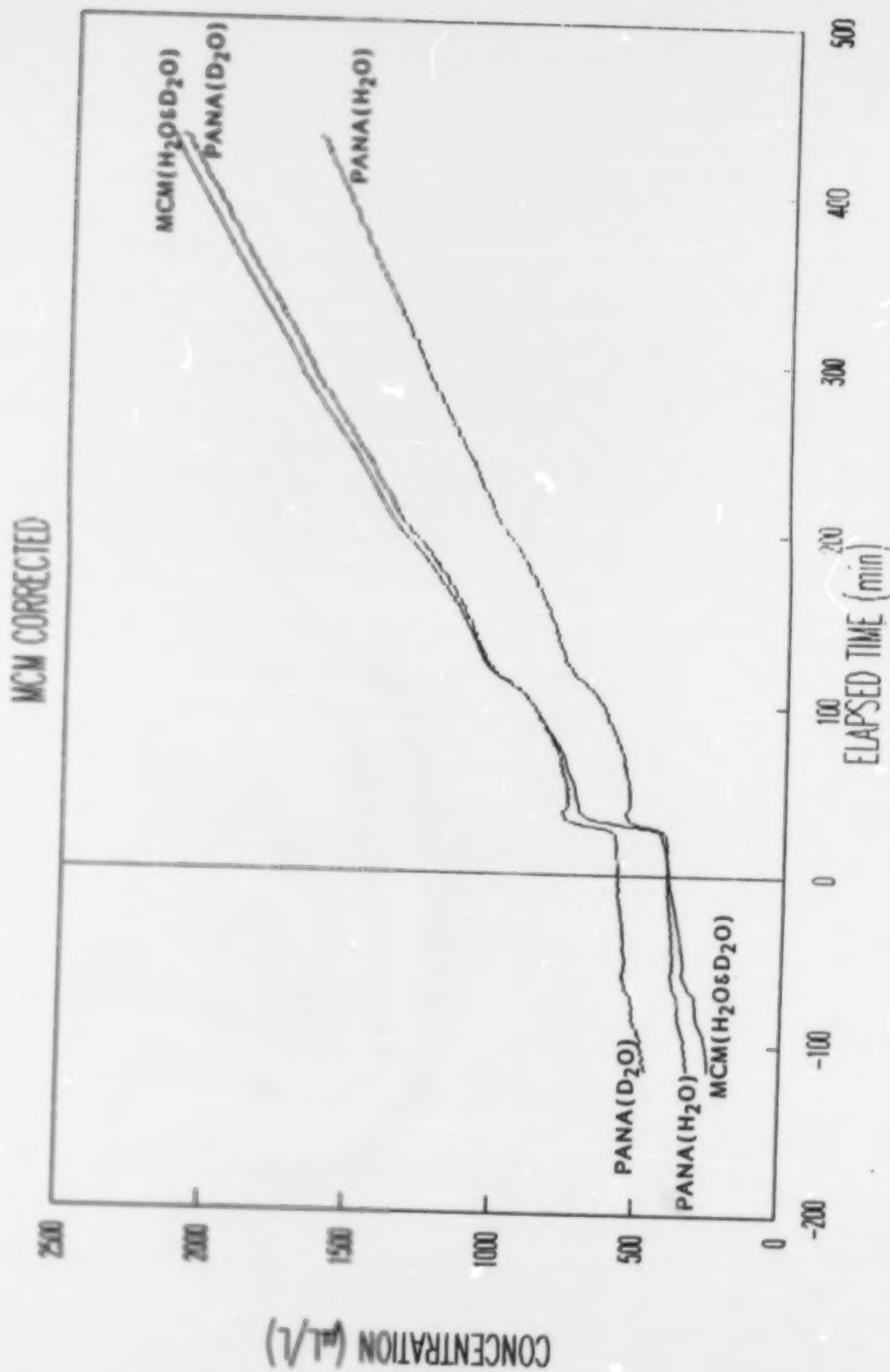


FIGURE D-9(b)
CONCENTRATION VS TIME FOR TEST 9 (MCM AND PANAMETRICS)

DARLINGTON AGS TEST 10

MCM CORRECTED

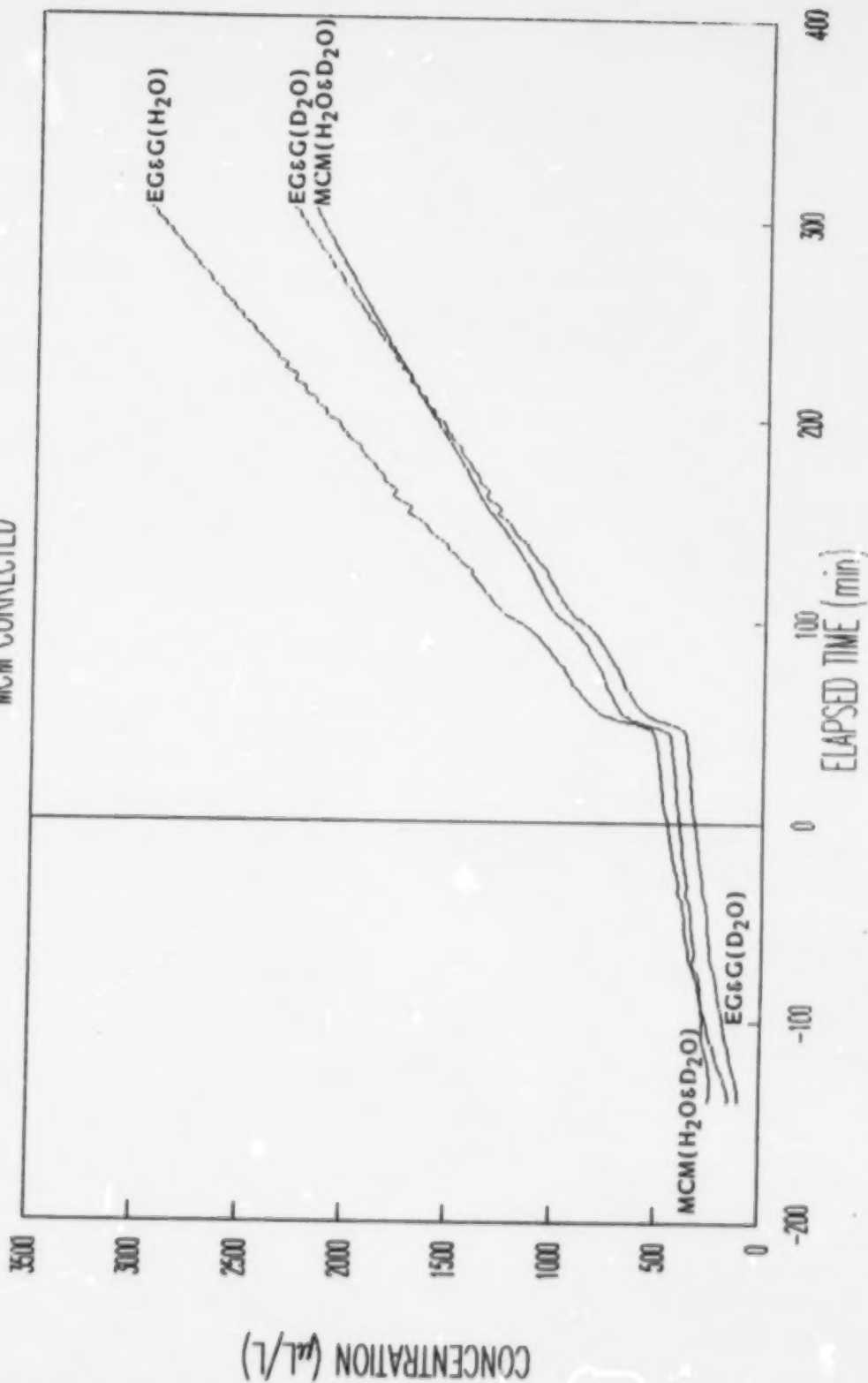


FIGURE D-10(a)

CONCENTRATION VS TIME FOR TEST 10 (MCM AND EG&G)

DARLINGTON AGS TEST 10

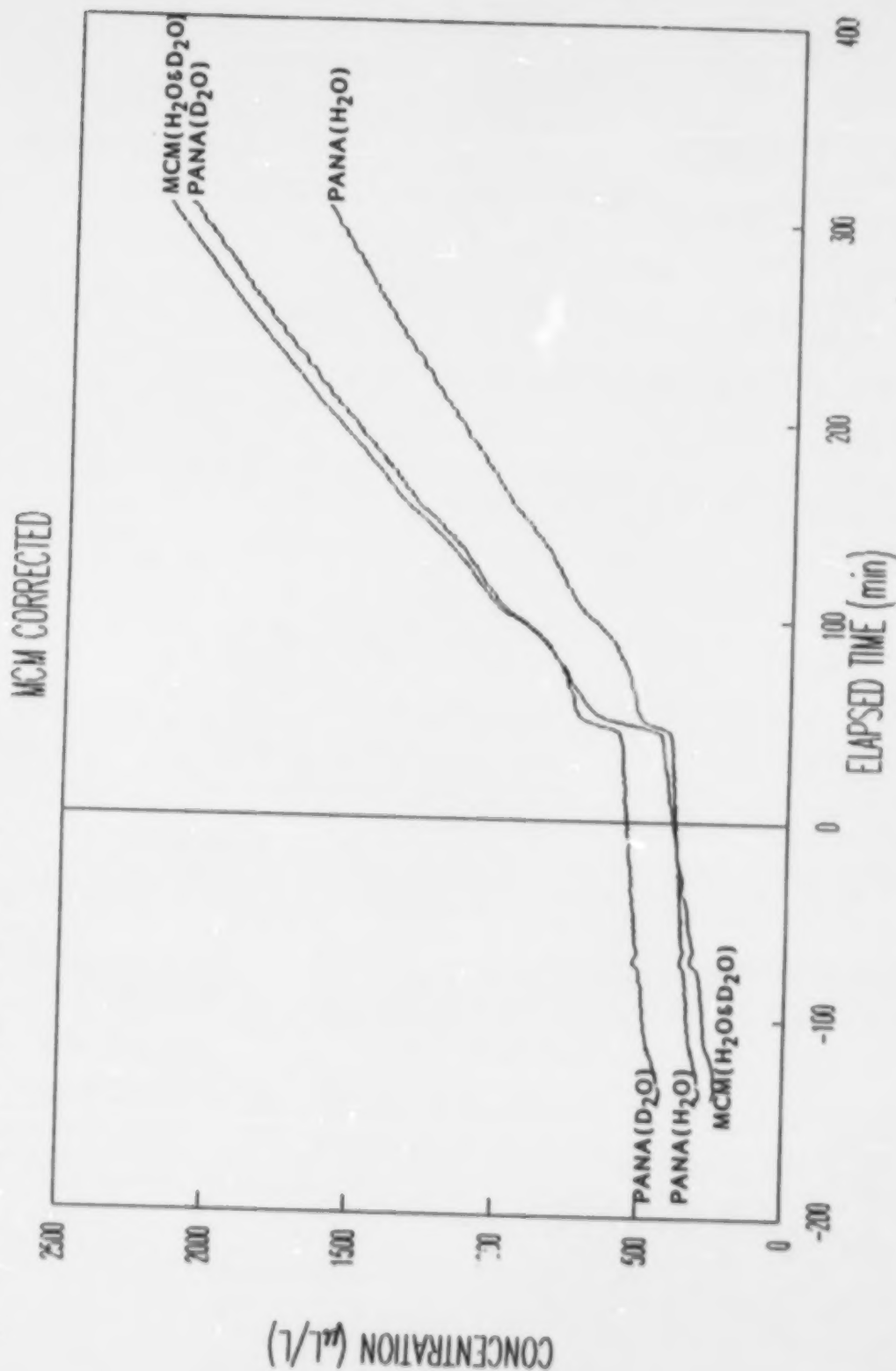


FIGURE D-10(b)

CONCENTRATION VS TIME FOR TEST 10 (MCM AND PANAMETRICS)

DARLINGTON AGS TEST 13

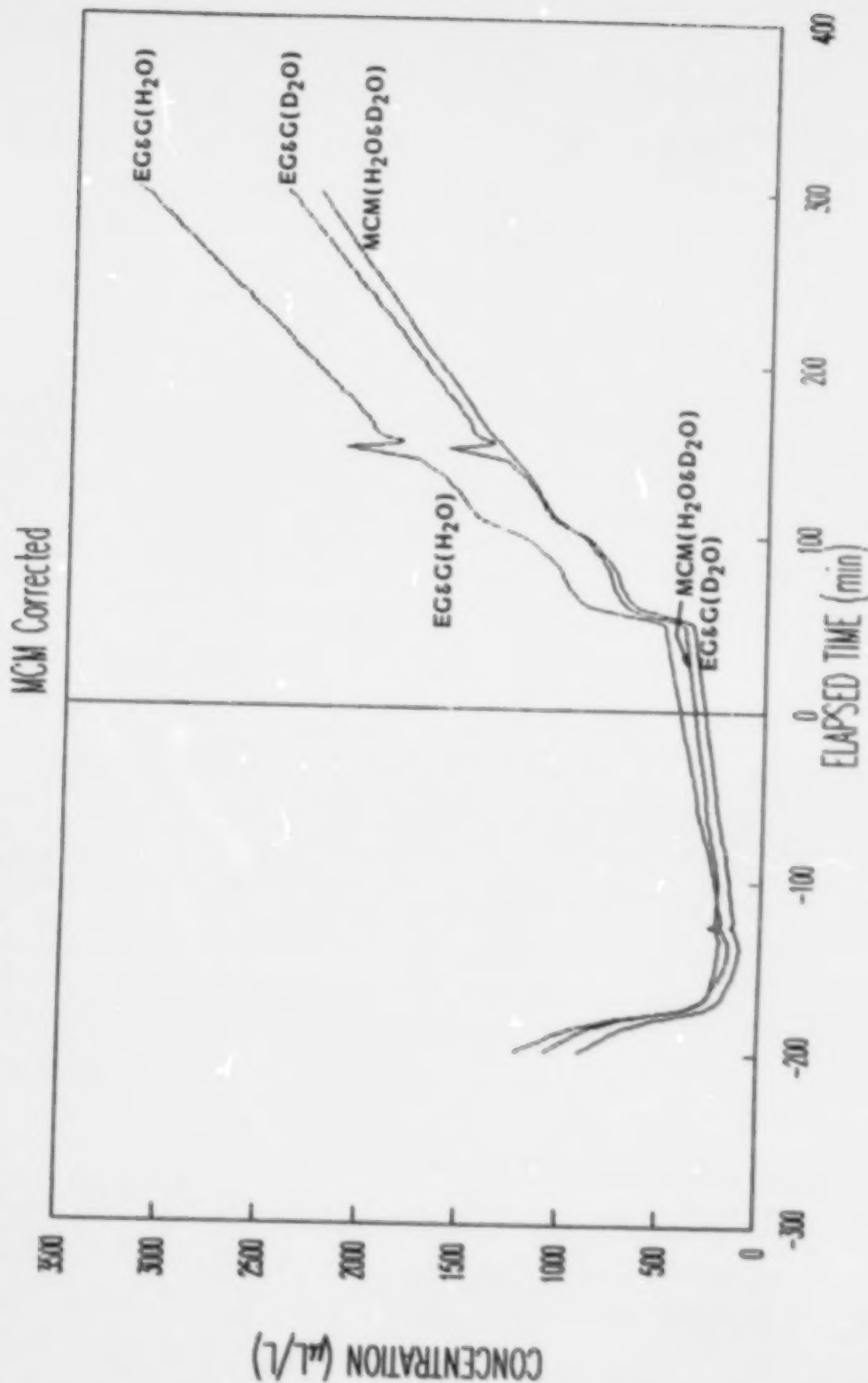


FIGURE D-13(a)
CONCENTRATION VS TIME FOR TEST 13 (MCM AND EG&G)

DARLINGTON AGS TEST 13

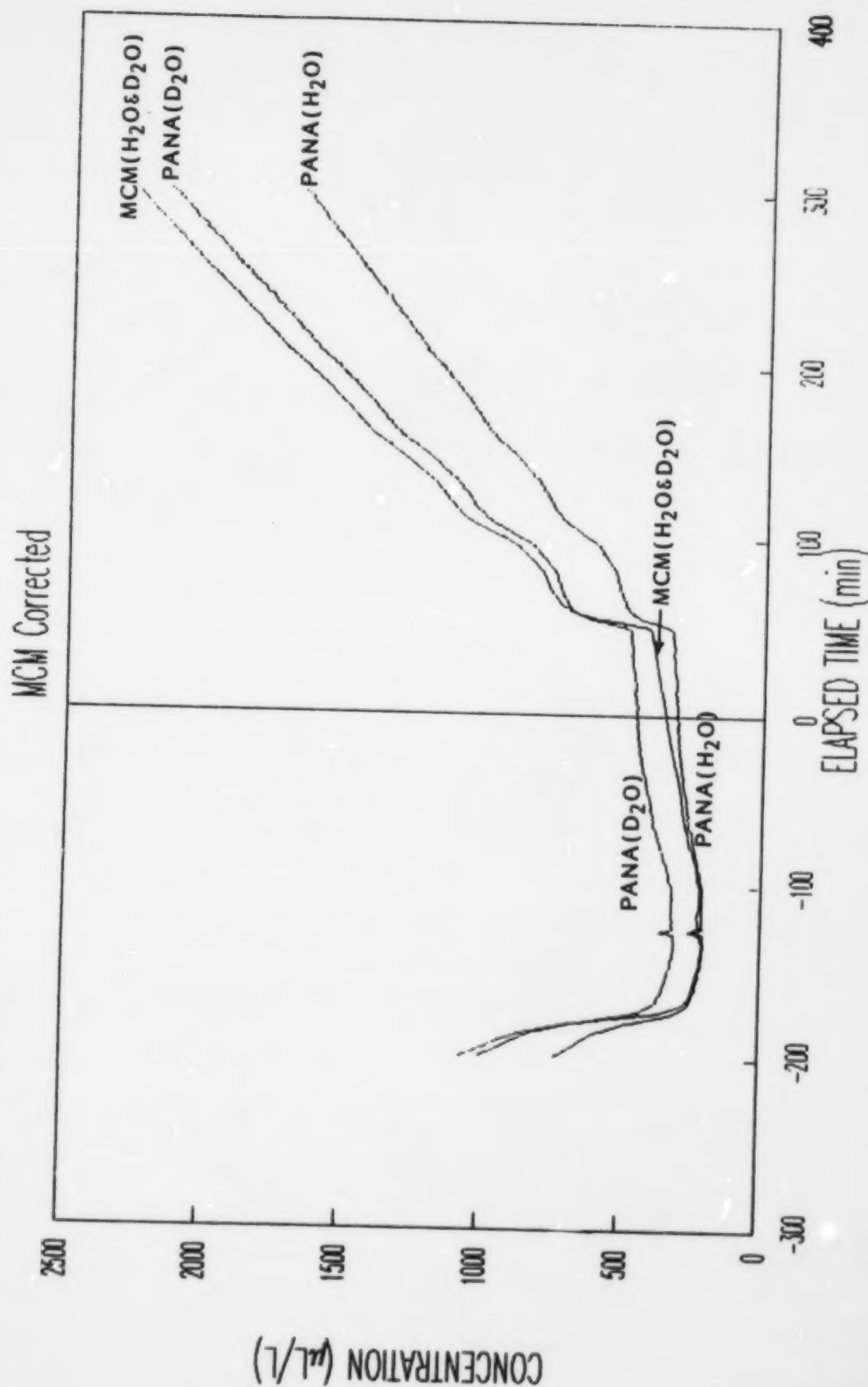


FIGURE D-13(b)
CONCENTRATION VS TIME FOR TEST 13 (MCM AND PANAMETRICS)

DARLINGTON AGS TEST 14

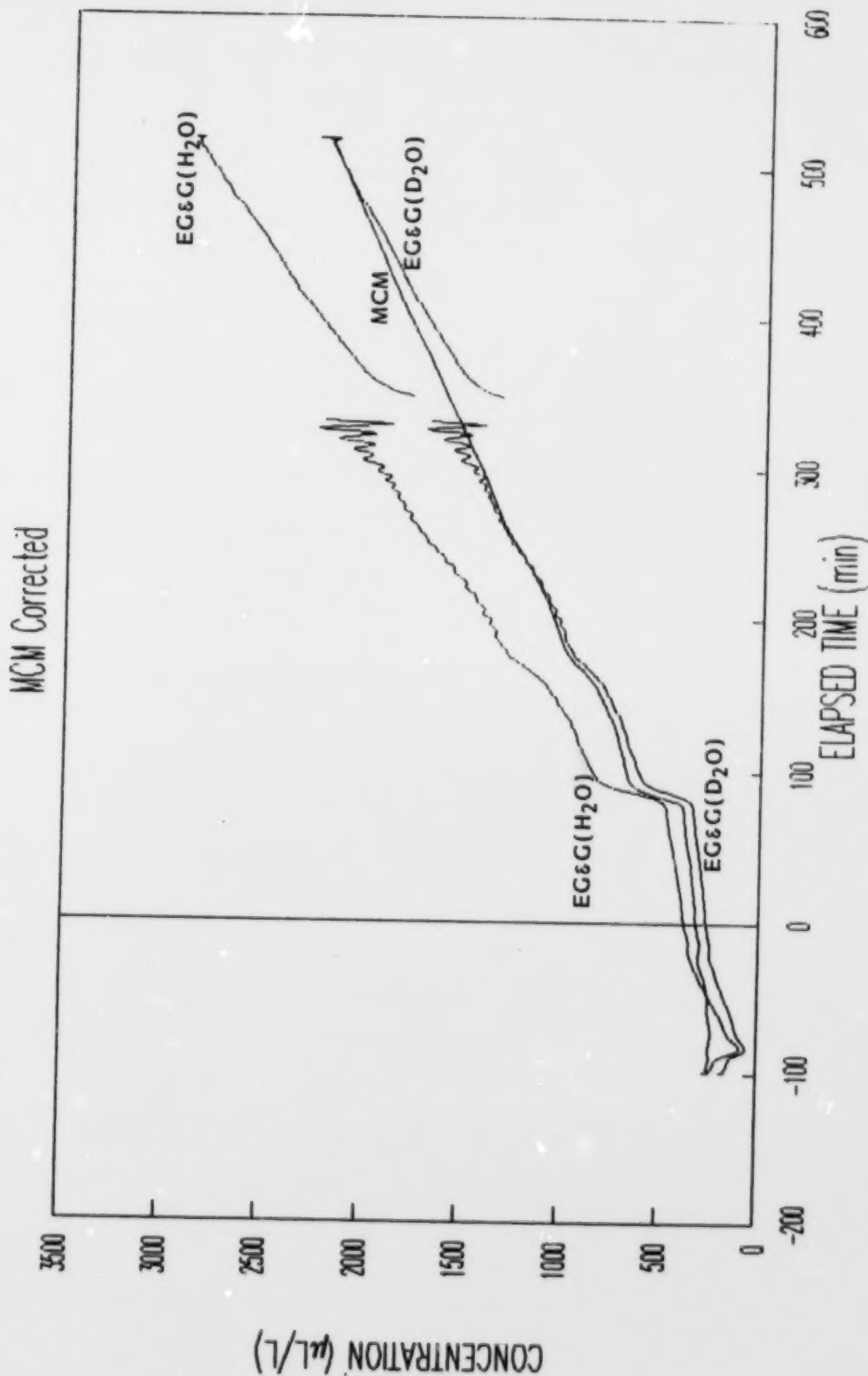


FIGURE D-14(a)
CONCENTRATION VS TIME FOR TEST 14 (MCM AND EG&G)

DARLINGTON AGS TEST 14

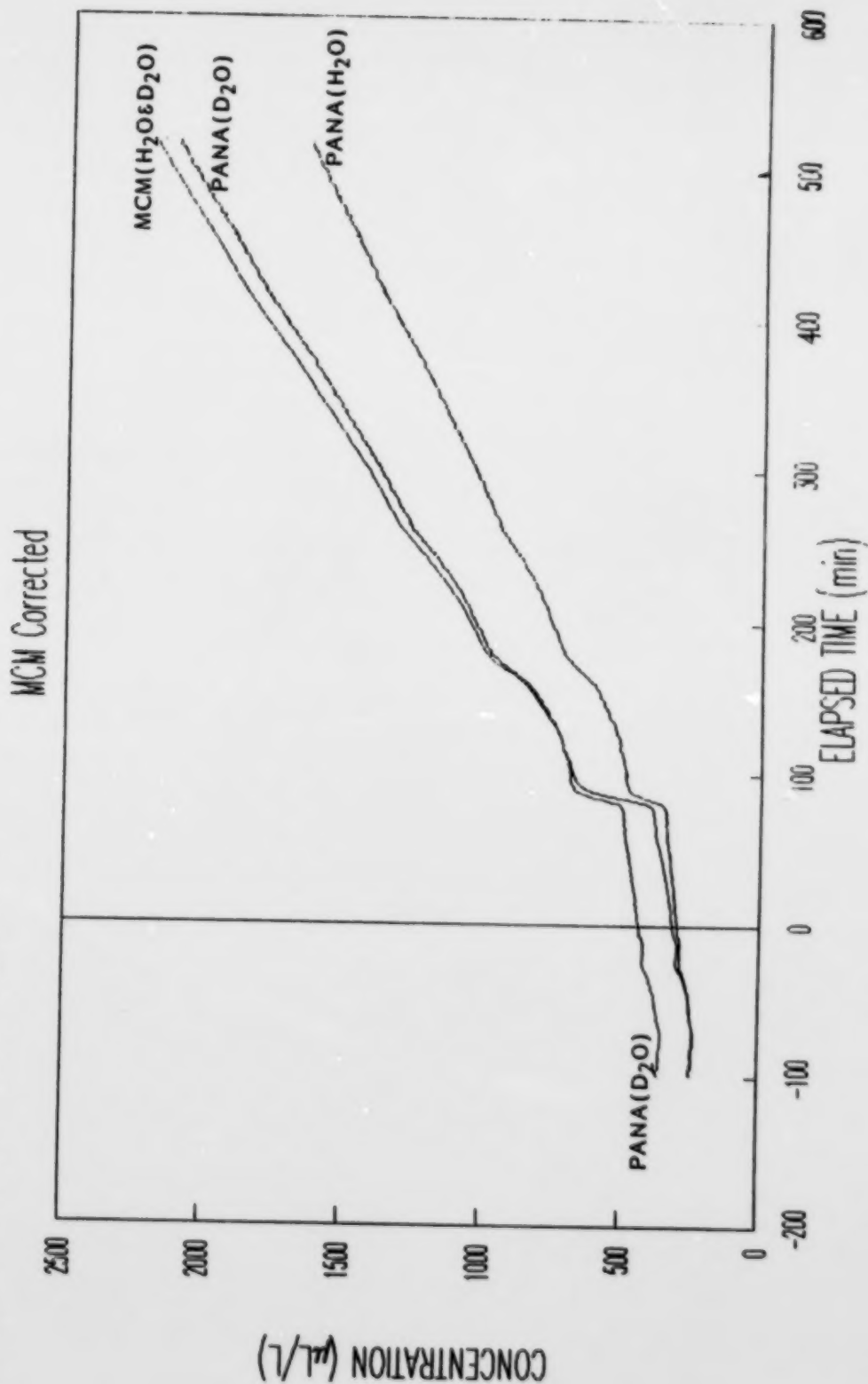


FIGURE D-14(b)

CONCENTRATION VS TIME FOR TEST 14 (MCM AND PANAMETRICS)

DARLINGTON AGS TEST 15

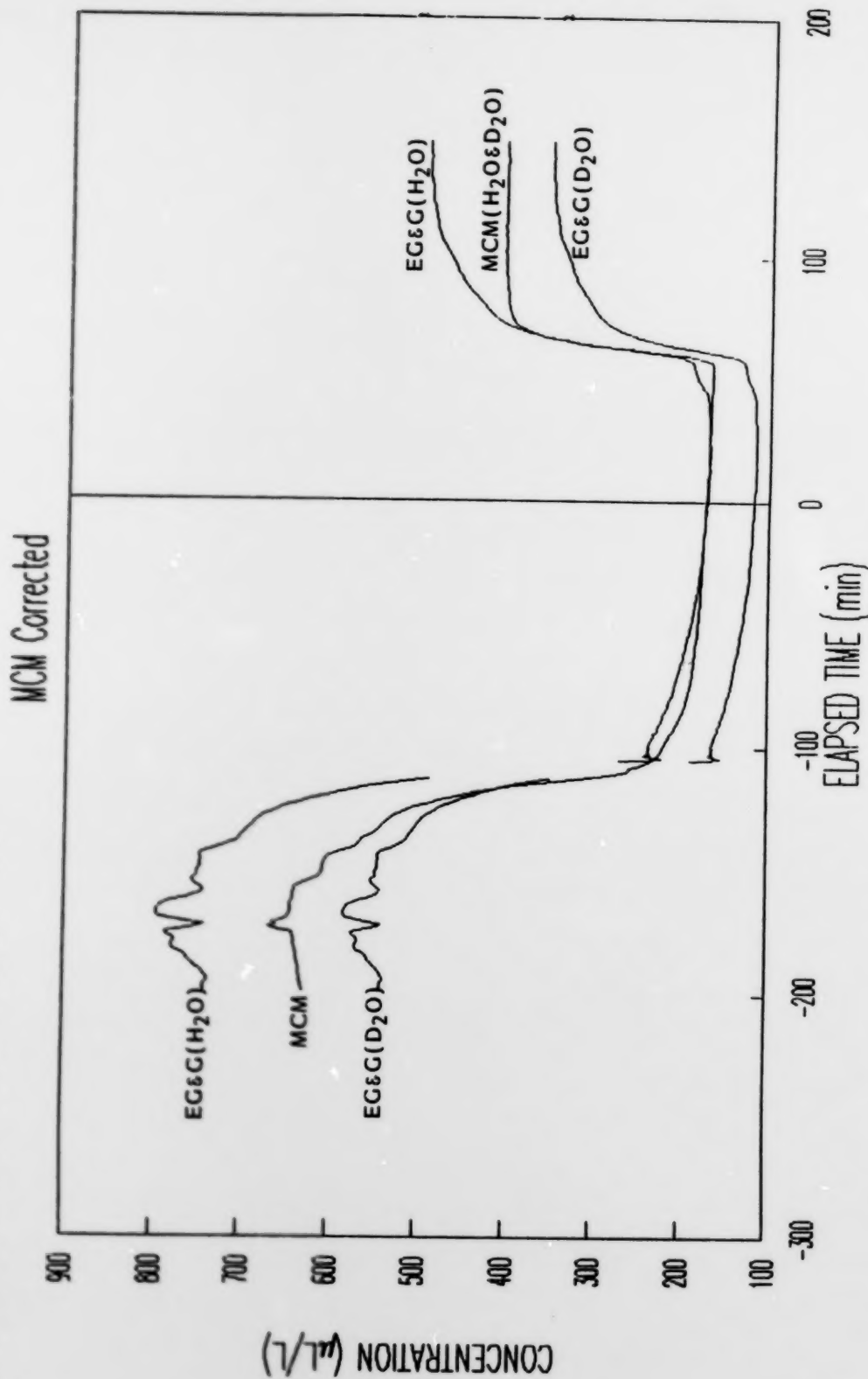


FIGURE D-15(a)
CONCENTRATION VS TIME FOR TEST 15 (MCM AND EG&G)

DARLINGTON AGS TEST 15

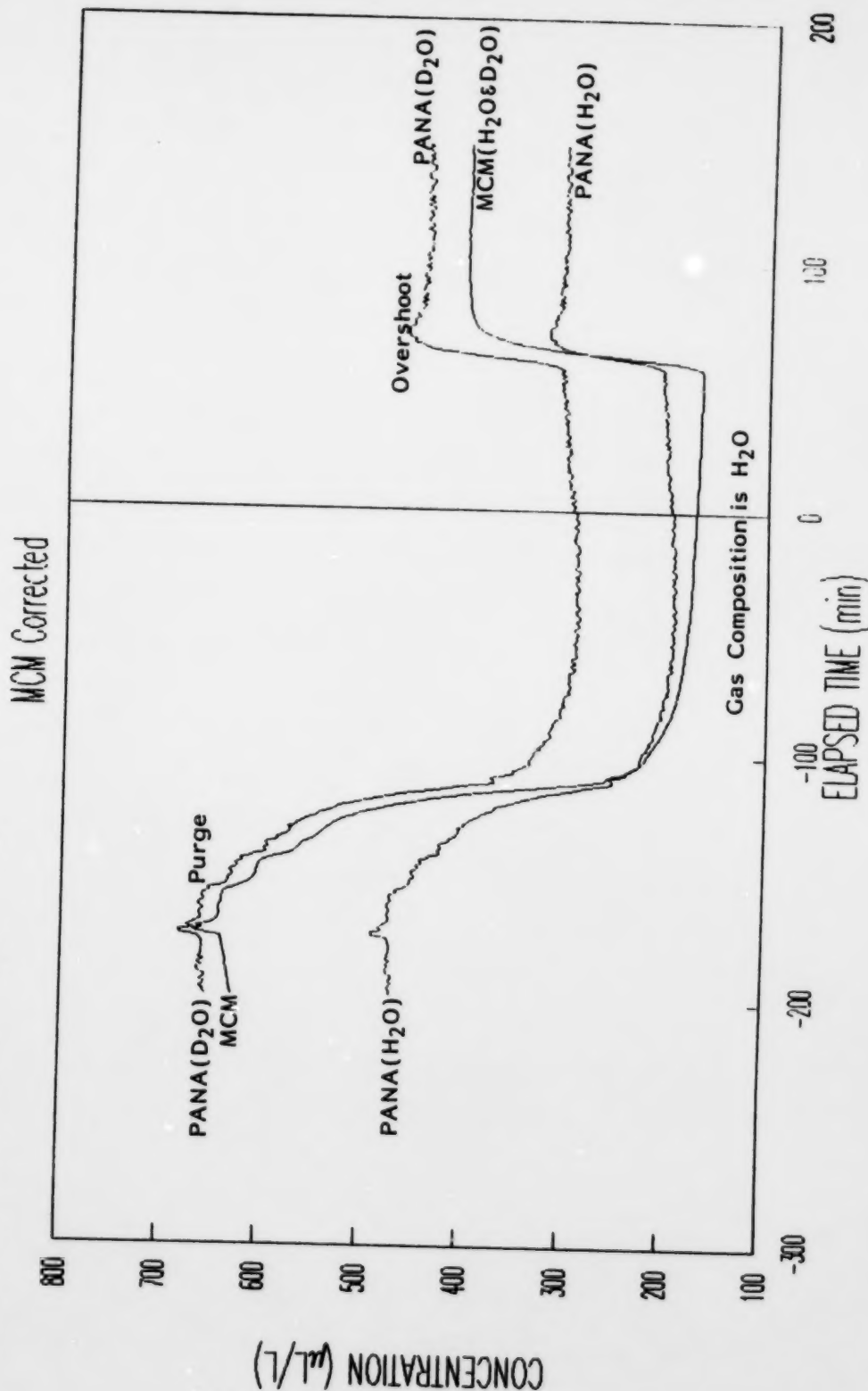


FIGURE D-15(b)
CONCENTRATION VS TIME FOR TEST 15 (MCM AND PANAMETRICS)

APPENDIX E

RATE OF CONCENTRATION INCREASE DATA

The graphs on the concentration increase rate with and without subtraction of the background increase rate are presented in Figures E.1 to E.15 as a function of time (note Figures E.7, E.11 and E.12 do not exist since tests 7, 11 and 12 were not carried out). The maximum rate of concentration increase after correction for the background increase rate and the time of its occurrence is summarized in Tables E.1 and E.2.

As shown in Figure E.16, the response of the Panametrics was noisy due to take off of the signal as is normal during calibration from the internal electronics rather than the recorder output. This resulted in a low level signal and this practice will be discontinued.

As shown in Figure E.17, the response of the EG&G hygrometer was significantly more noisy than that of the MCM resulting probably from the hunting nature of its response.

TABLE E.1 MAXIMUM RATE OF CONCENTRATION INCREASE AND TIME OF OCCURRENCE
(CORRECTED FOR BACKGROUND INCREASE)

TEST NUMBER	INJECTION LOCATION	INJ RATE (G/HR)	FIRST PEAK RATE U/L/MIN CORRECTED FOR PRESSURE AND BACKGROUND	SECOND PEAK RATE U/L/MIN	STRING RATE (1/MIN) $\Delta P/\Delta T$ PRESS	FIRST PEAK TIME (MIN)	SECOND PEAK TIME (MIN)	COMMENTS
1	EXT	10.8	8.09	20.0	8.8/5.15	79.8	79.8	COLD VS HOT FOR EXT INJ SEE NOTE 1
3	1 CH 12 CH	5.1 5.05	29.5 16.8	9.7 8.44	7.5/5.77 7.55/5.64	22.3 86.7	96.3 140	CHANNEL LENGTH EFFECT COLD REACTOR NOTE 2
8	1 CH 12 CH	4.3 4.3	33.7 22.9	14.4 13.5	6.53/4.98 6.58/4.85	18.8 52.8	70.5 107	CHANNEL LENGTH EFFECT HOT REACTOR NOTE 3

NOTES

1 ALTHOUGH THE INJECTION RATE FOR COLD TEST 1 WAS HIGHER THAN FOR HOT TEST 6, THE RATE OF RISE OF CONCENTRATION WAS LOWER AND THE PEAKS WERE DELAYED BY 8 TO 55 MIN; THE DIFFERENCE IN TIMES BETWEEN THE FIRST AND SECOND PEAKS WERE 50 AND 33 MIN FOR THE COLD AND HOT TESTS, RESPECTIVELY.

2 THE RATE OF CONC RISE WAS MUCH HIGHER FOR THE SHORTEST STRING; THE FIRST PEAK TIMES APPEARED PROPORTIONAL TO STRING LENGTH; THE DIFFERENCE IN TIMES BETWEEN THE FIRST AND SECOND PEAKS WAS ABOUT 75 MIN (ALL COLD TESTS).

3 THE RATE OF CONC RISE WAS SIGNIFICANTLY HIGHER FOR THE SHORTEST STRING (FIRST PEAK) AT THE SAME INJECTION RATE; ALTHOUGH THE INJECTION RATE WAS LOWER FOR THESE HOT TESTS, THE RATE OF RISE WAS TWICE THAT OF THE COLD TESTS. ALSO, ALTHOUGH THE STRING LENGTH WAS MORE THAN 10% SLOWER FOR THE HOT TESTS, THE FIRST PEAK APPEARED SOONER THAN IN THE COLD TESTS. THE DIFFERENCE IN TIMES BETWEEN THE FIRST AND SECOND PEAKS WAS ABOUT 53 MIN FOR THE HOT TESTS COMPARED TO 75 MIN FOR THE COLD TESTS.

TABLE E.2. MAXIMUM RATE OF CONCENTRATION INCREASE AND TIME OF OCCURRENCE (CORRECTED FOR PRESSURE AND BACKGROUND INCREASE)

TEST NUMBER	INJECTION LOCATION	IN/AVE (G/IN)	FIRST PLAS DATE	SECOND PLAS DATE	STRING PLAS DATE	FIRST PLAS TIME (MIN)	SECOND PLAS TIME (MIN)	COMMENTS
100	2 EN	2.3	22.3	9.7	7.53.77	33.3	39.3	COLD VS NORMAL VS LOW FLOW NOTE 4
	2 EN	2.3	22.3	9.05	7.53.77	33.3	39.3	
101	11 EN	4.23	35.3	6.84	7.55.47	31.9	137	COLD VS NORMAL VS LOW FLOW NOTE 5
102	12 EN	5.03	34.3	8.44	7.55.36	34.7	149	COLD VS NORMAL VS LOW FLOW NOTE 6
	12 EN	5.3	34.3	7.73	7.55.36	34.7	149	
103	13 EN	5.09	18.9	8.44	7.52.00	33.7	140	SINGLE PASS VS RECIRC COLD
	13 EN	5.3	18.3	13.5	7.52.00	33.7	140	SINGLE PASS VS RECIRC COLD
104	13 EN	5.09	18.9	13.5	7.52.00	33.7	107	SINGLE PASS VS RECIRC HOT
	13 EN	5.3	18.3	13.5	7.52.00	33.7	107	

Notes

STRING FLOW RATE AT PRESSURE X FIRST PEAK TIME WAS 128 L FOR THE COLD TEST 3 WHICH COMPARES WELL WITH THE CALCULATED VALUE OF 120 L FOR CHANNEL 1. STRING FLOW RATE AT PRESSURE X FIRST PEAK TIME = 93 SUGGESTING A GAS TEMPERATURE OF 1260°K X 208 = 40 K & 130 DEG C IN THE FOUR CHANNEL STRING.

5 STRING FLOW X FIRST PEAK TIME = $5.47 \times 61 = 334$ WHICH APPROXIMATES 11 CHANNELS $\times$ 31.5L = 346L

6 GAS TEMPERATURE ESTIMATE (344 X 200)/(4.01 X 47.9) = 447 K = 175°C IN THE 11 CHANNEL STRING

7 STRING FLOW X FIRST PEAK TIME = $5.64 \times 66.7 = 376$ WHICH APPROXIMATES 12 CHANNELS X $31.51 = 378$.

STRING FLOW X FIRST PEAK TIME = 255 TO 262; GAS TEMPERATURE ESTIMATE = 164 DEG C IN THE 12 CHANNELS

9 GAS TEMPERATURE ESTIMATE = 174 DEG C IN THE 12 CHANNEL STRING

TABLE E.3 RATIO OF RATE OF RISE OF WATER VAPOR CONCENTRATION NEAR START AND END OF TEST

TEST	INJECTION RATE AT END OF TEST G/H	UL/L/MIN AT END PRESSURE AND BACKGROUND CORRECTED	UL/L/MIN INJECTION RATE AT END	INJECTION RATE START OF TEST	UL/L/MIN AT PEAK	UL/L/MIN INJECTION RATE START	UL/L/MIN DIVIDED BY END	CHANNELS STRING	COMPRESSORS RUNNING
UNPURGE	10.4	12.2	1.17	11.2	3.4 *	3.64	3.11	12	PURGE
	4.0	3.8	1.15	2.4	29.1	3.62	4.23	12	
	4.8	5.51	1.15	5.3	16.9	3.19	2.77	12	
PURGE	10.2	4.84	1.1	10.6	8.09 *	0.83	10.68	2	PURGE
	3.4	5.0	1.48	2.4	22.7	10.62	7.25	2	
	2.4	5.0	1.48	2.4	22.7	7.25	7.25	2	
	3.4	2.0	1.27	3.4	28.1	8.32	9.79	2	

* MULTIPLIED BY 12 TO ALLOW FOR 4 STRINGS RESPONSE WITH INJECTION INTO 48 STRINGS

DARLINGTON AGS TEST 1

Cold Tests

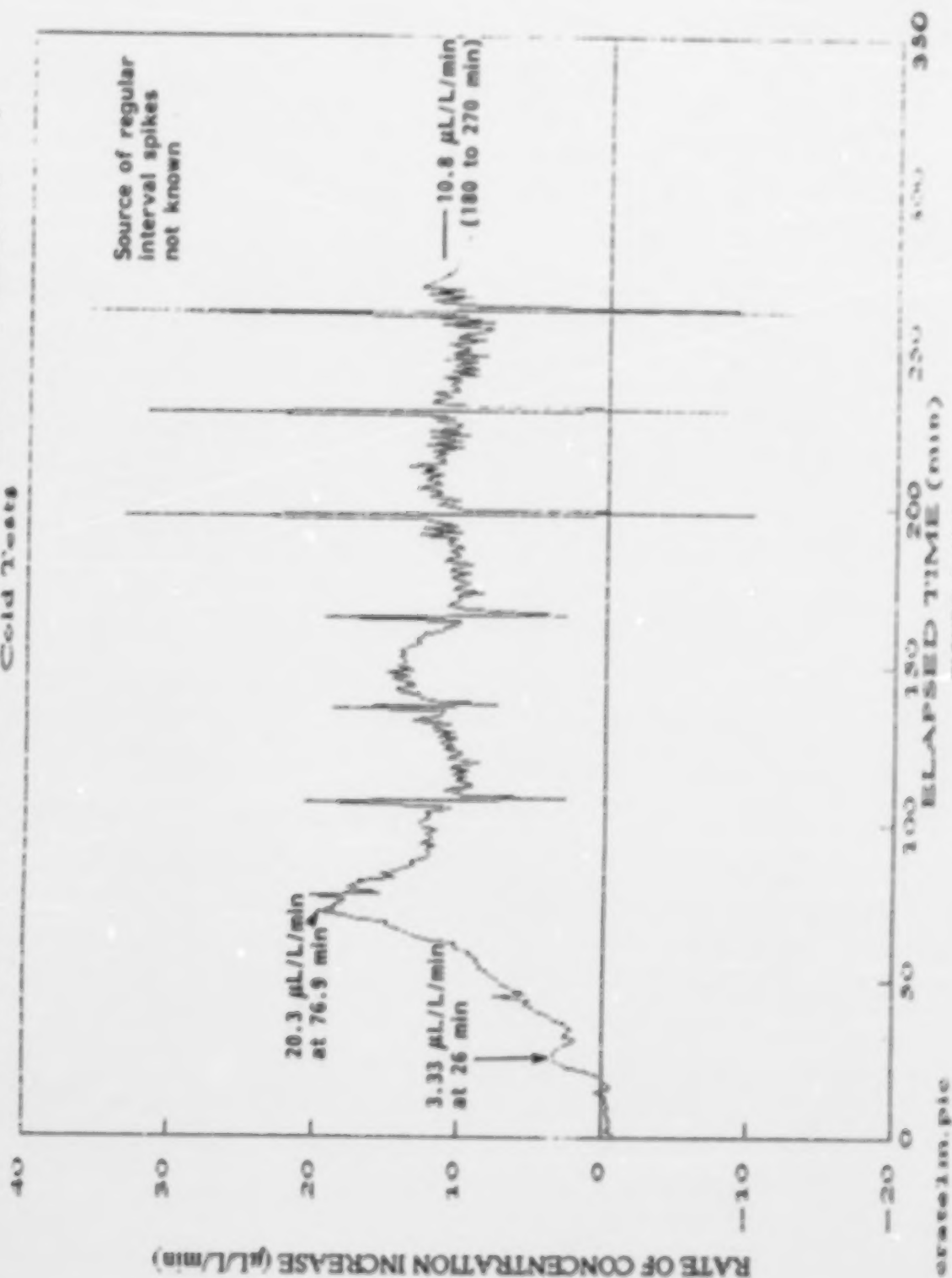


FIGURE E-1(a)

CONCENTRATION INCREASE RATE VS TIME
UNCORRECTED FOR BACKGROUND AND PRESSURE INCREASE

DARLINGTON AGS TEST 1

Cold Tests

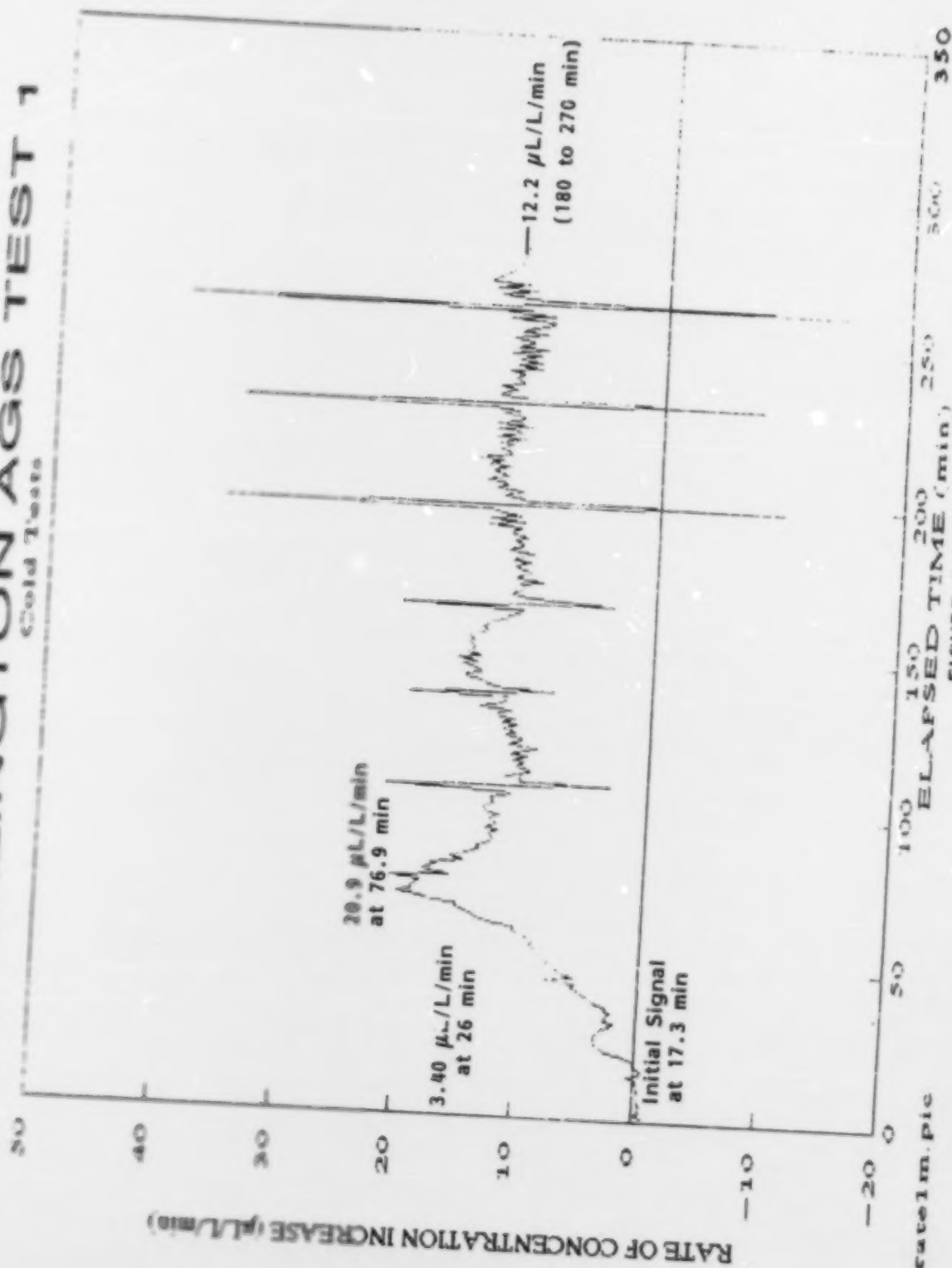


FIGURE E-1(b)
CONCENTRATION INCREASE RATE VS TIME
(CORRECTED FOR BACKGROUND AND PRESSURE INCREASE)

DARLINGTON AGS TEST 2

Cold Tests

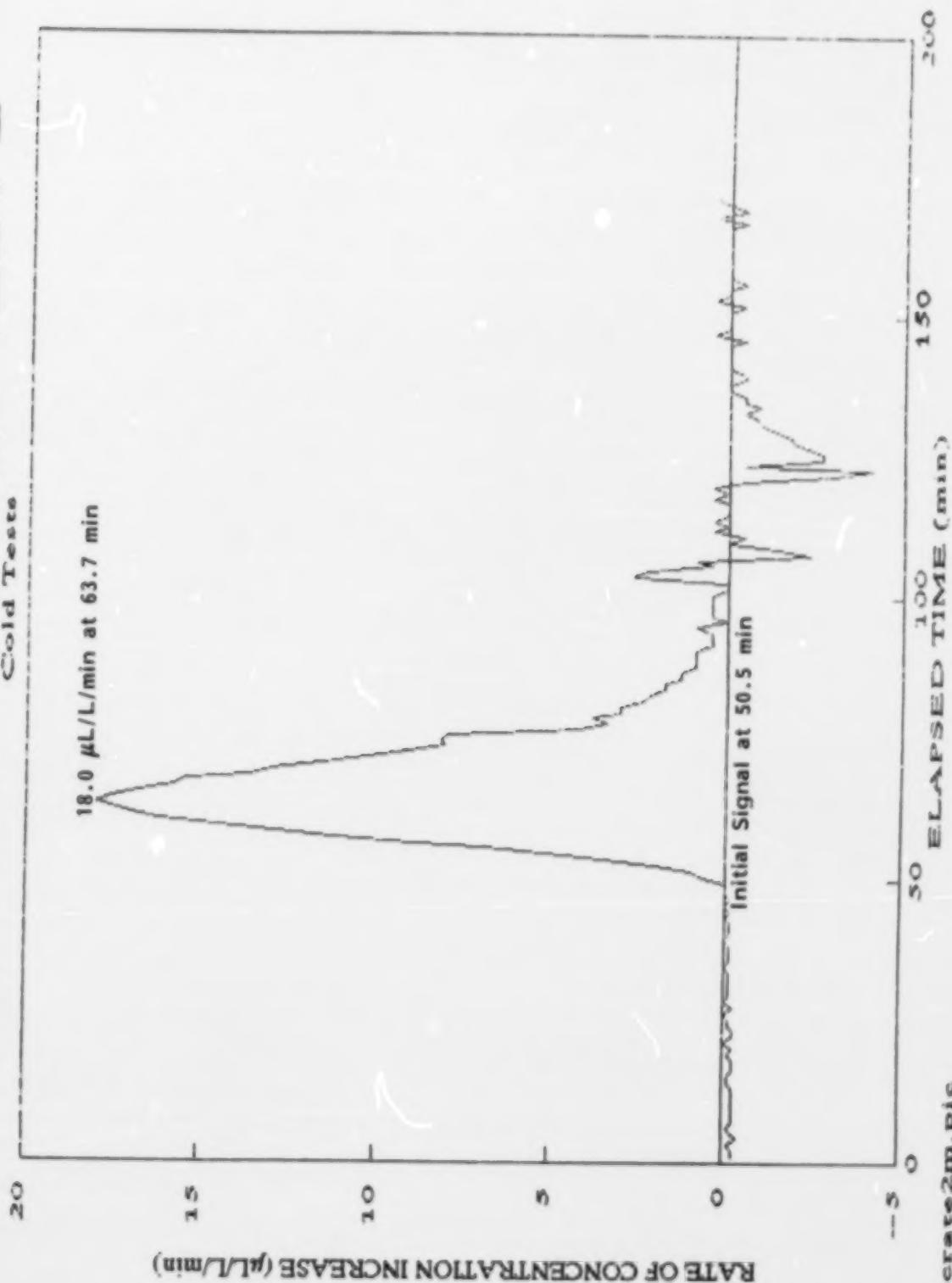


FIGURE E-2

CONCENTRATION INCREASE RATE VS TIME
(CORRECTION FOR BACKGROUND AND PRESSURE INCREASE UNNECESSARY)

DARLINGTON AGS TEST 3

Cold Tests

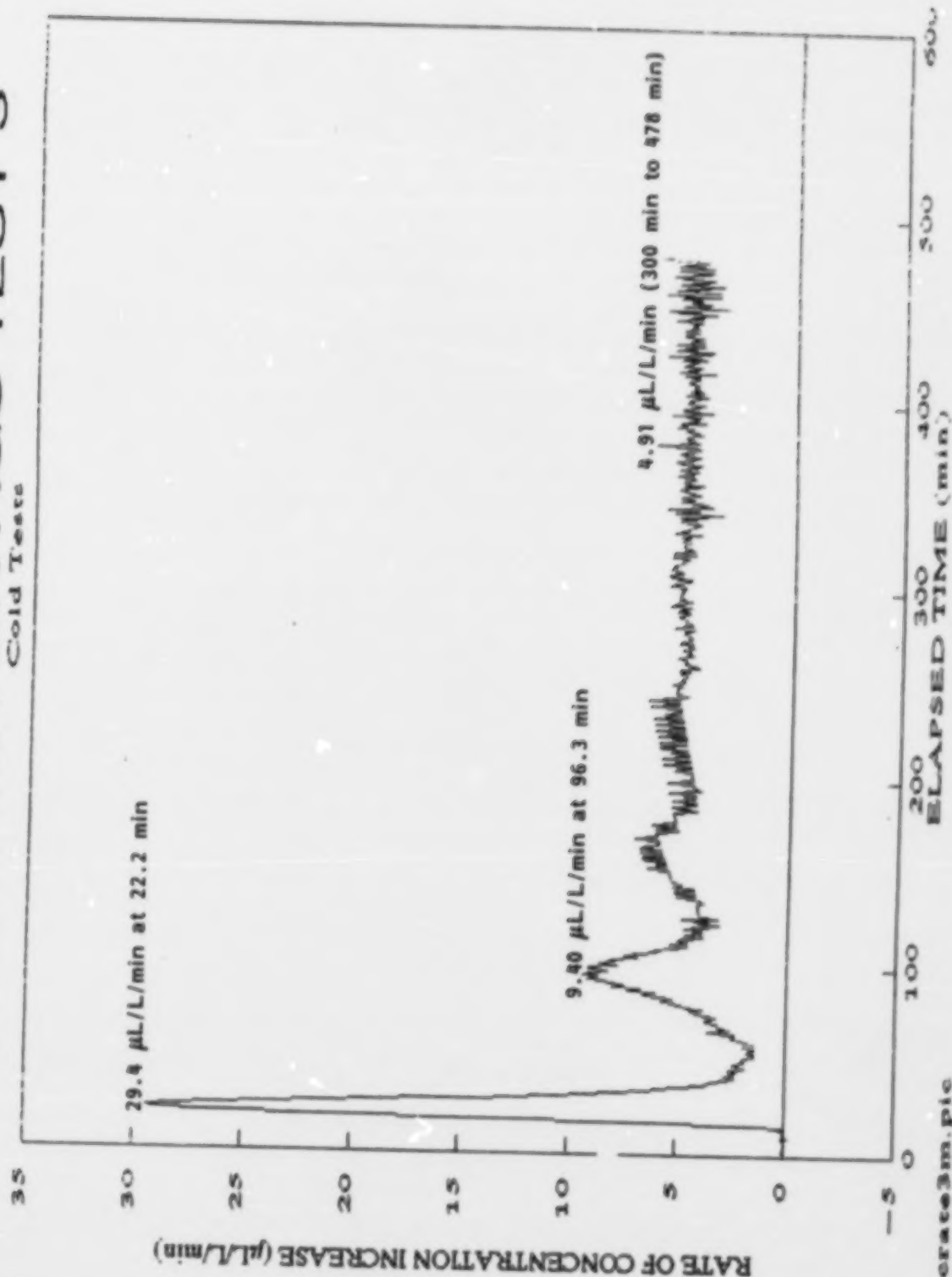


FIGURE E-3(a)
CONCENTRATION INCREASE RATE VS TIME
(UNCORRECTED FOR BACKGROUND AND PRESSURE INCREASE)

DARLINGTON AGS TEST 3

Cold Tests

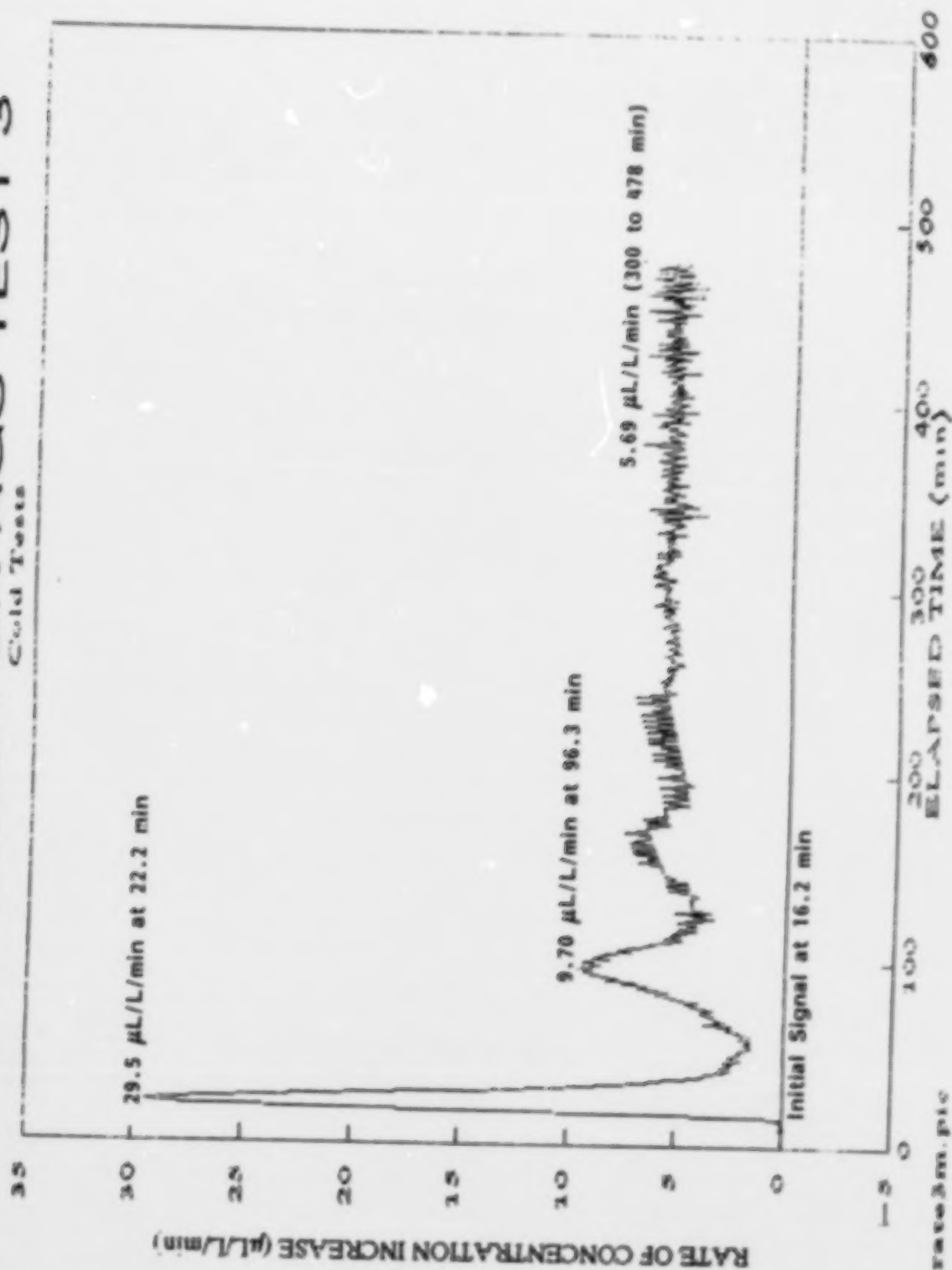


FIGURE E-3(b)
CONCENTRATION INCREASE RATE VS TIME
(CORRECTED FOR BACKGROUND AND PRESSURE INCREASE)

DARLINGTON AGS TEST 4

Cold Tests

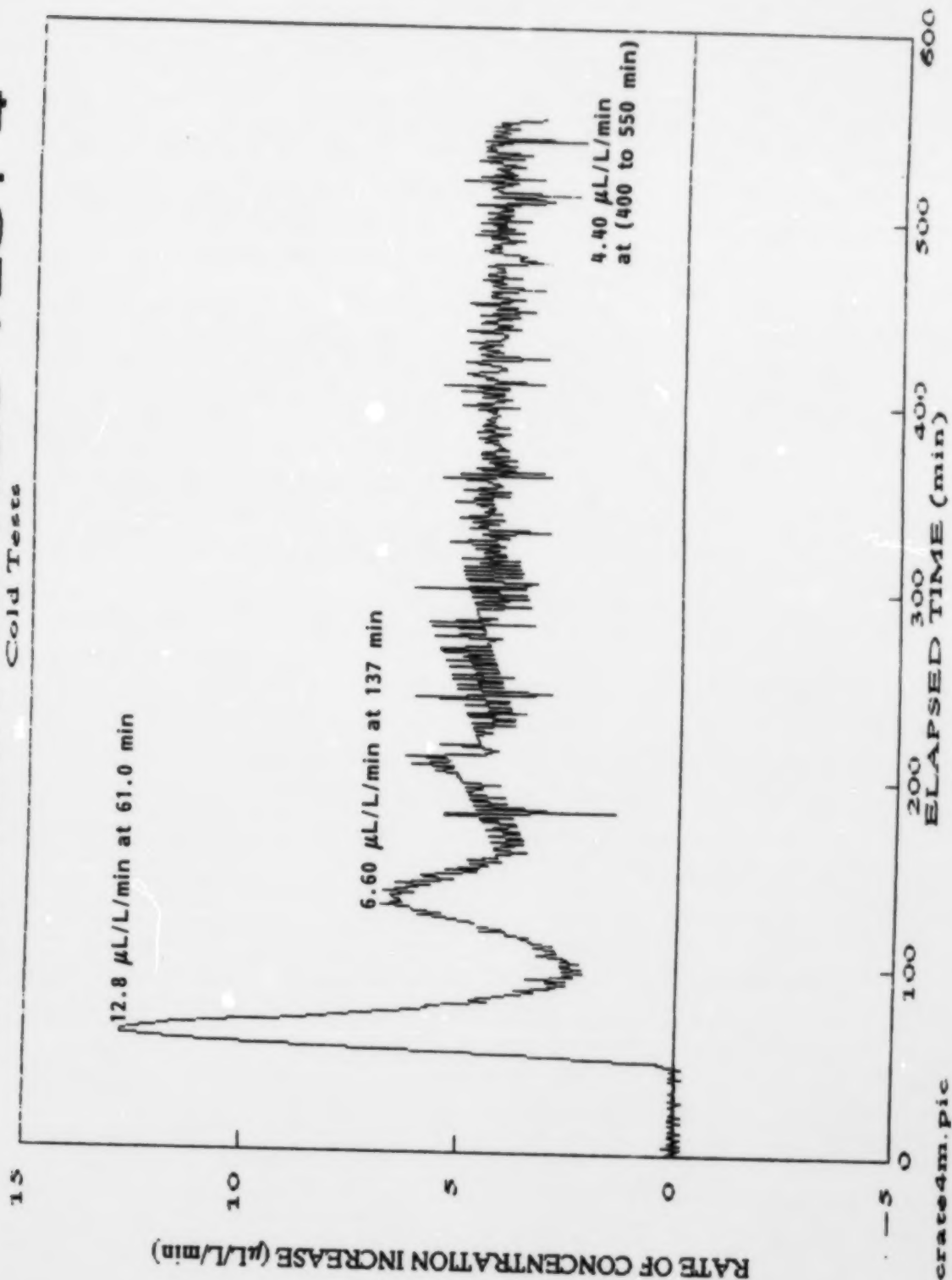


FIGURE E-4(a)
CONCENTRATION INCREASE RATE VS TIME
(UNCORRECTED FOR BACKGROUND AND PRESSURE INCREASE)

DARLINGTON AGS TEST 4

Cold Tests

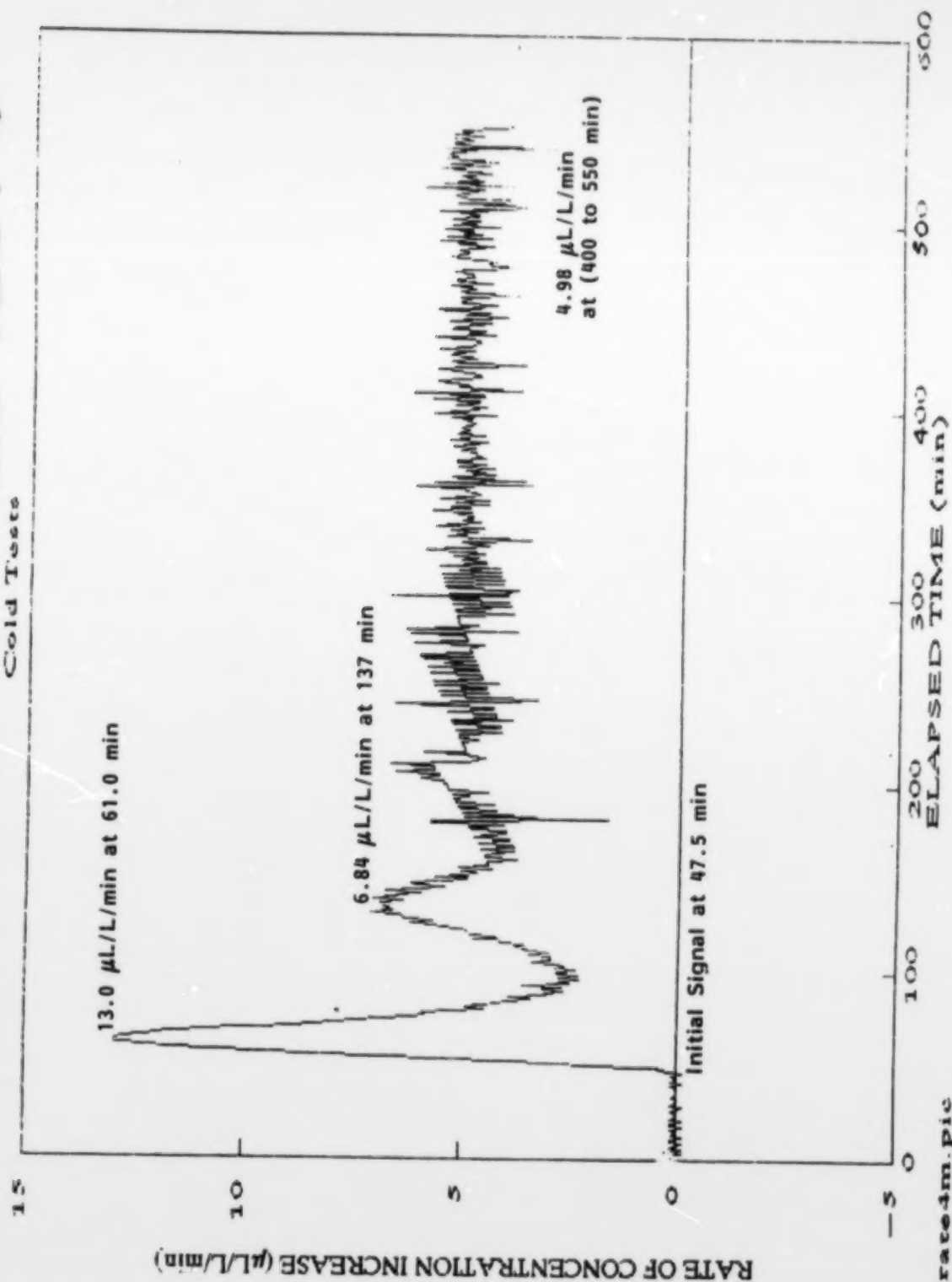


FIGURE E-4(b)
CONCENTRATION INCREASE RATE VS TIME
(CORRECTED FOR BACKGROUND AND PRESSURE INCREASE)

DARLINGTON AGS TEST 5

Cold Tests

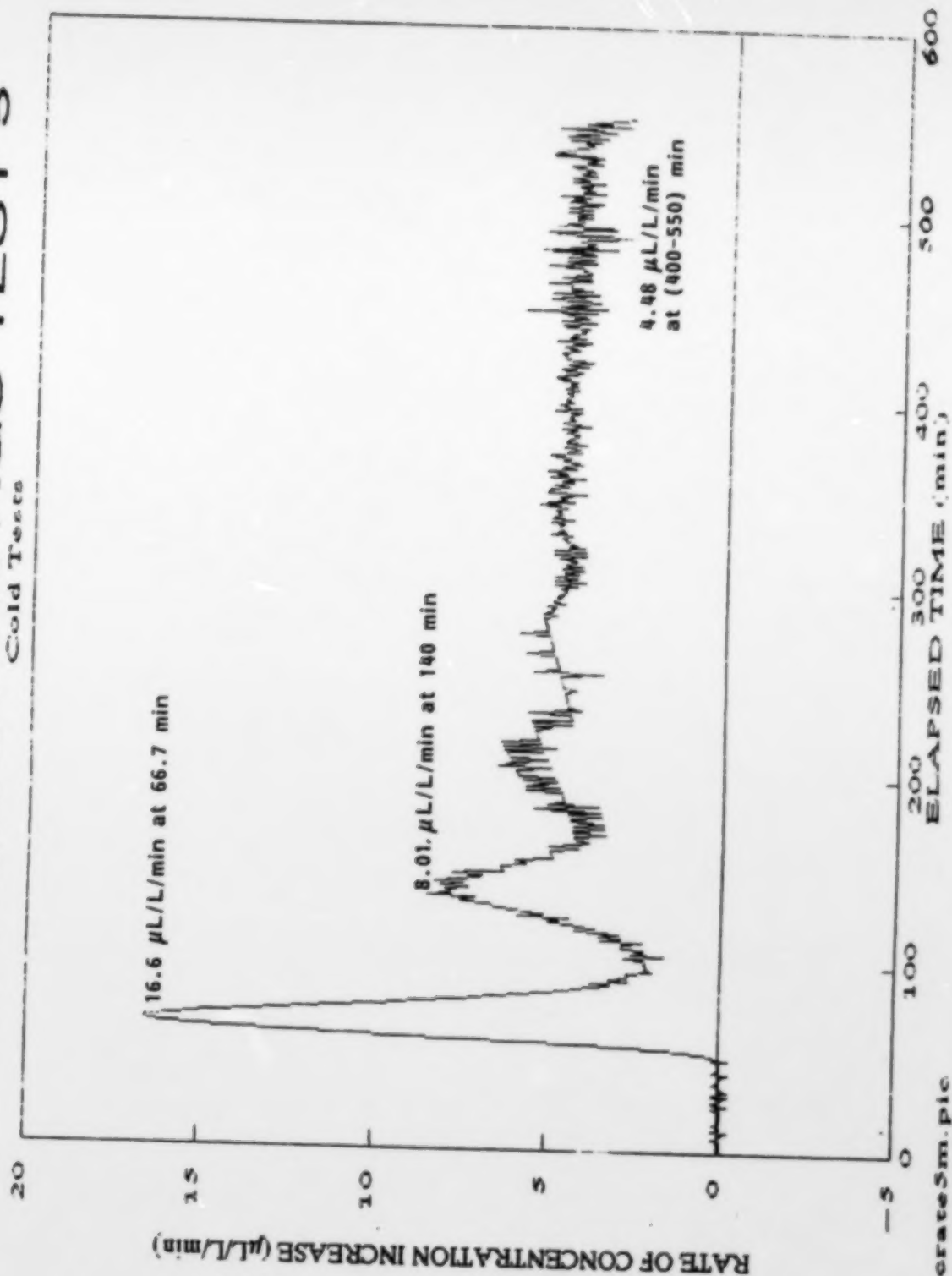


FIGURE E-5(a)
CONCENTRATION INCREASE RATE VS TIME
(UNCORRECTED FOR BACKGROUND AND PRESSURE INCREASE)

DARLINGTON AGS TEST 5

Cold Tests

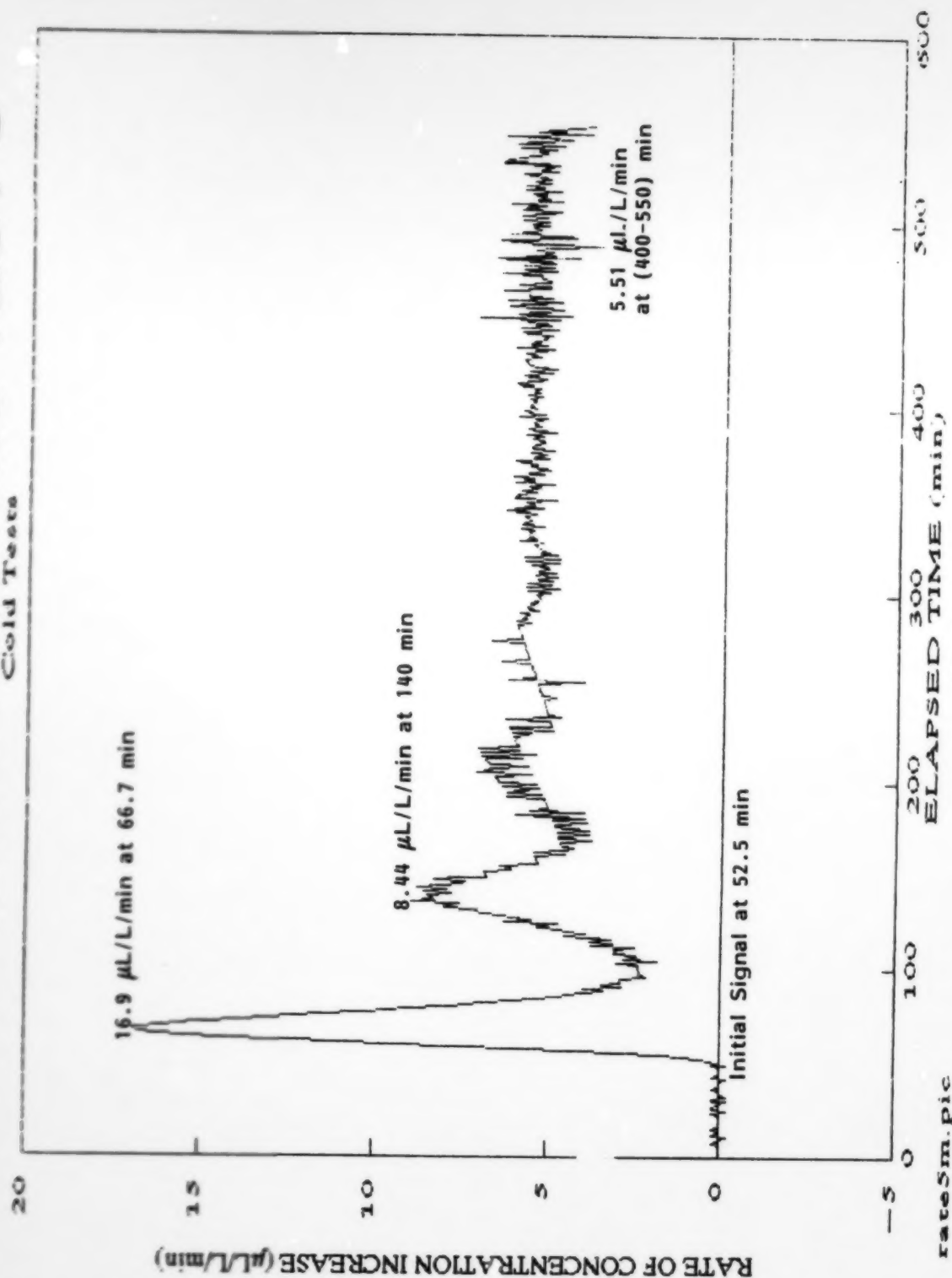


FIGURE E-5(b)
CONCENTRATION INCREASE RATE VS TIME
(CORRECTED FOR BACKGROUND AND PRESSURE INCREASE)

DARLINGTON AGS TEST 6

MCM Concentration Partially Corrected

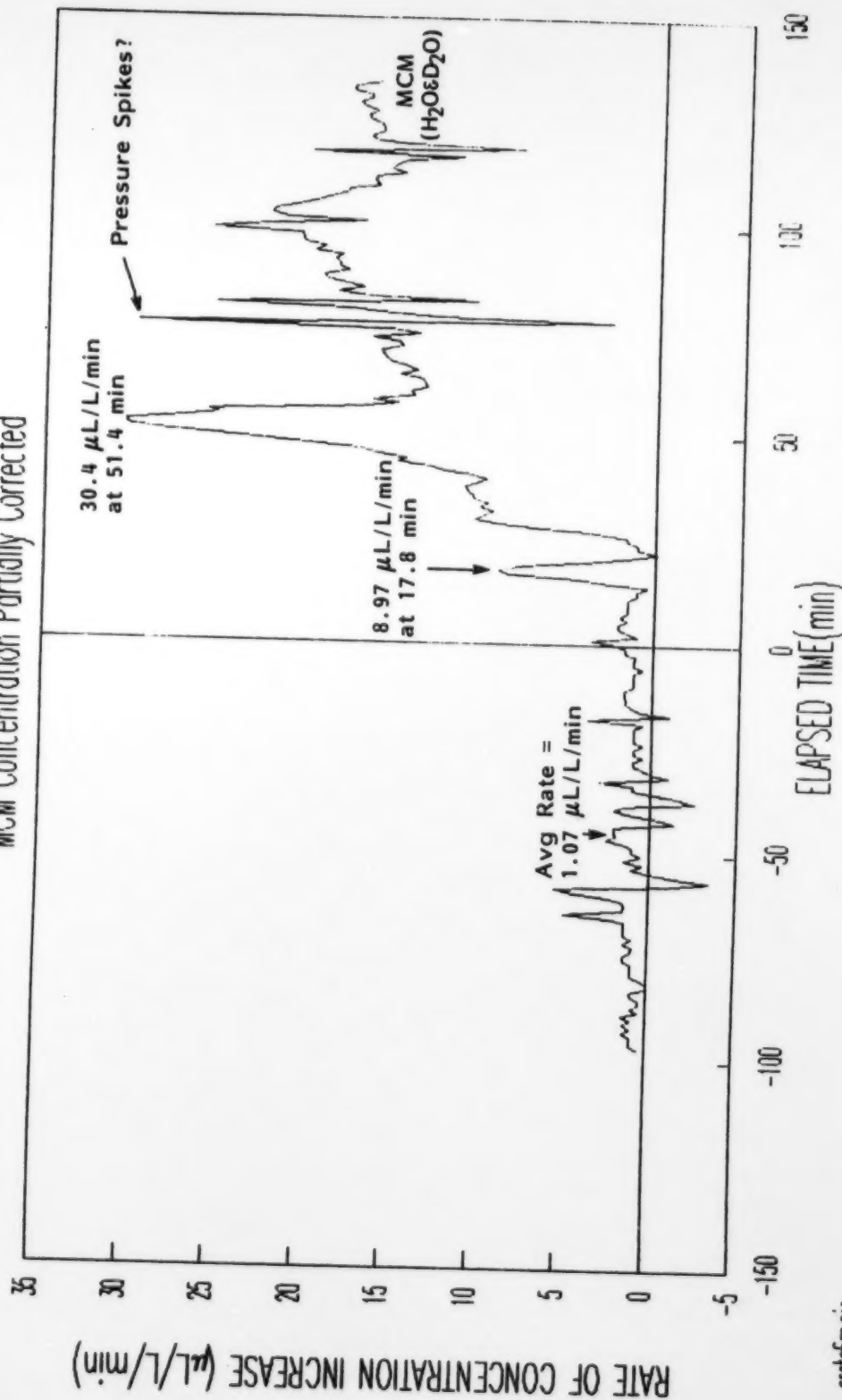


FIGURE E-6(a)
CONCENTRATION INCREASE RATE VS TIME
(UNCORRECTED FOR BACKGROUND AND PRESSURE INCREASE)

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DARLINGTON AGS TEST 6

MCM Concentration Partially Corrected

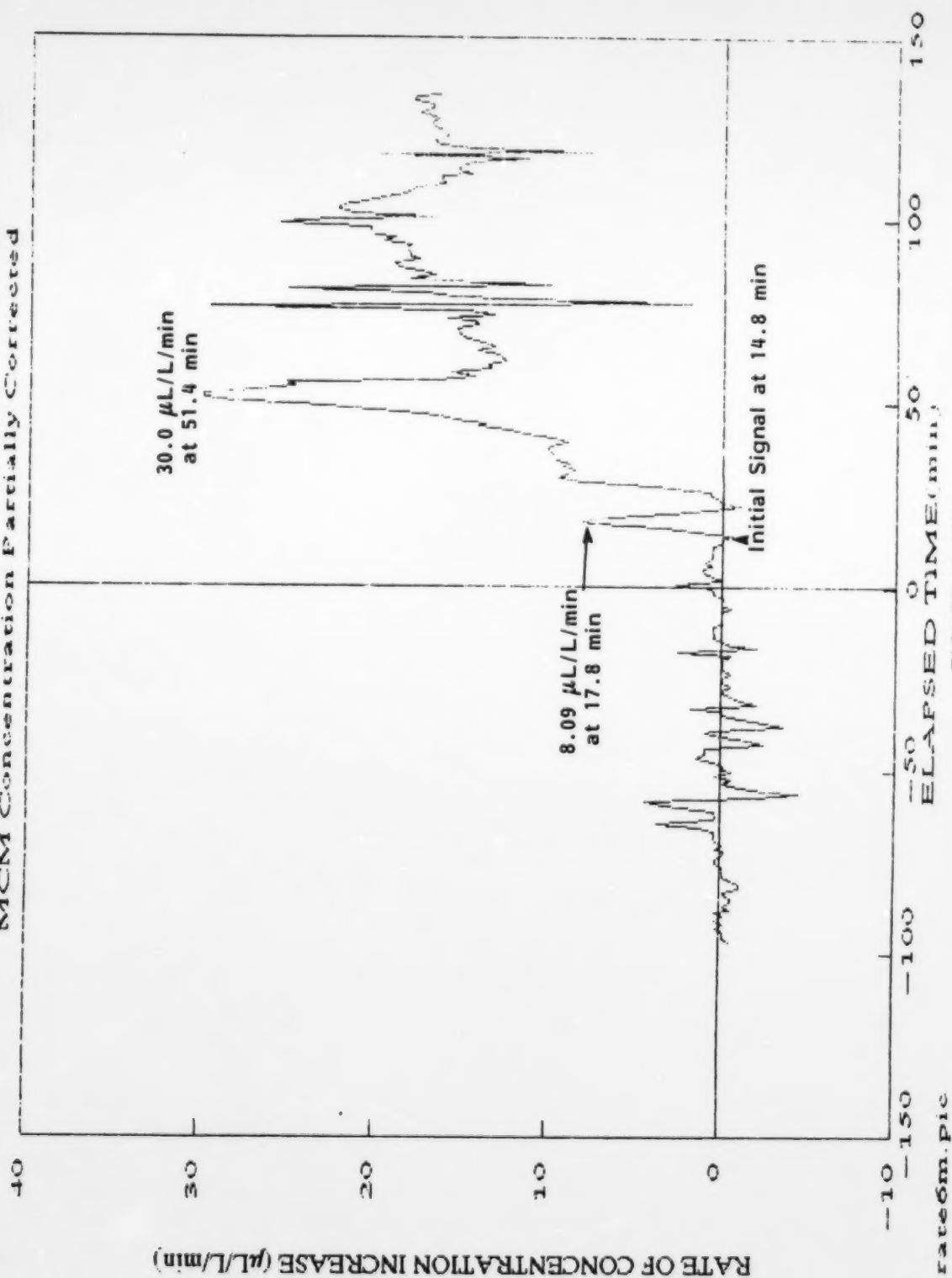
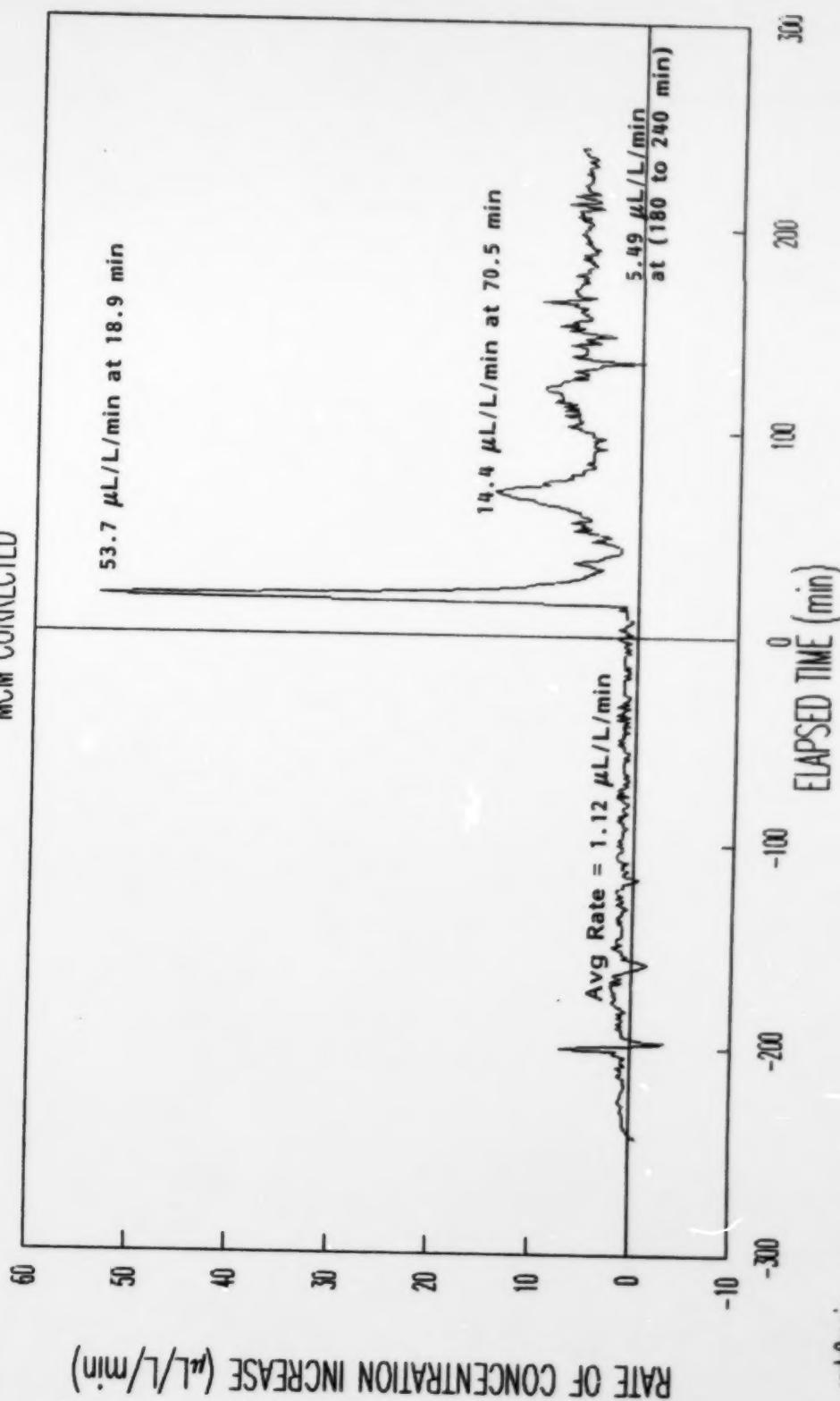


FIGURE E-6(b)
CONCENTRATION INCREASE RATE VS TIME
(CORRECTED FOR BACKGROUND AND PRESSURE INCREASE)

DARLINGTON AGS TEST 8

MCM CORRECTED



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FIGURE E-8(a)

CONCENTRATION INCREASE RATE VS TIME
(UNCORRECTED FOR BACKGROUND AND PRESSURE INCREASE)

DARLINGTON AGS TEST 8

MCM CORRECTED

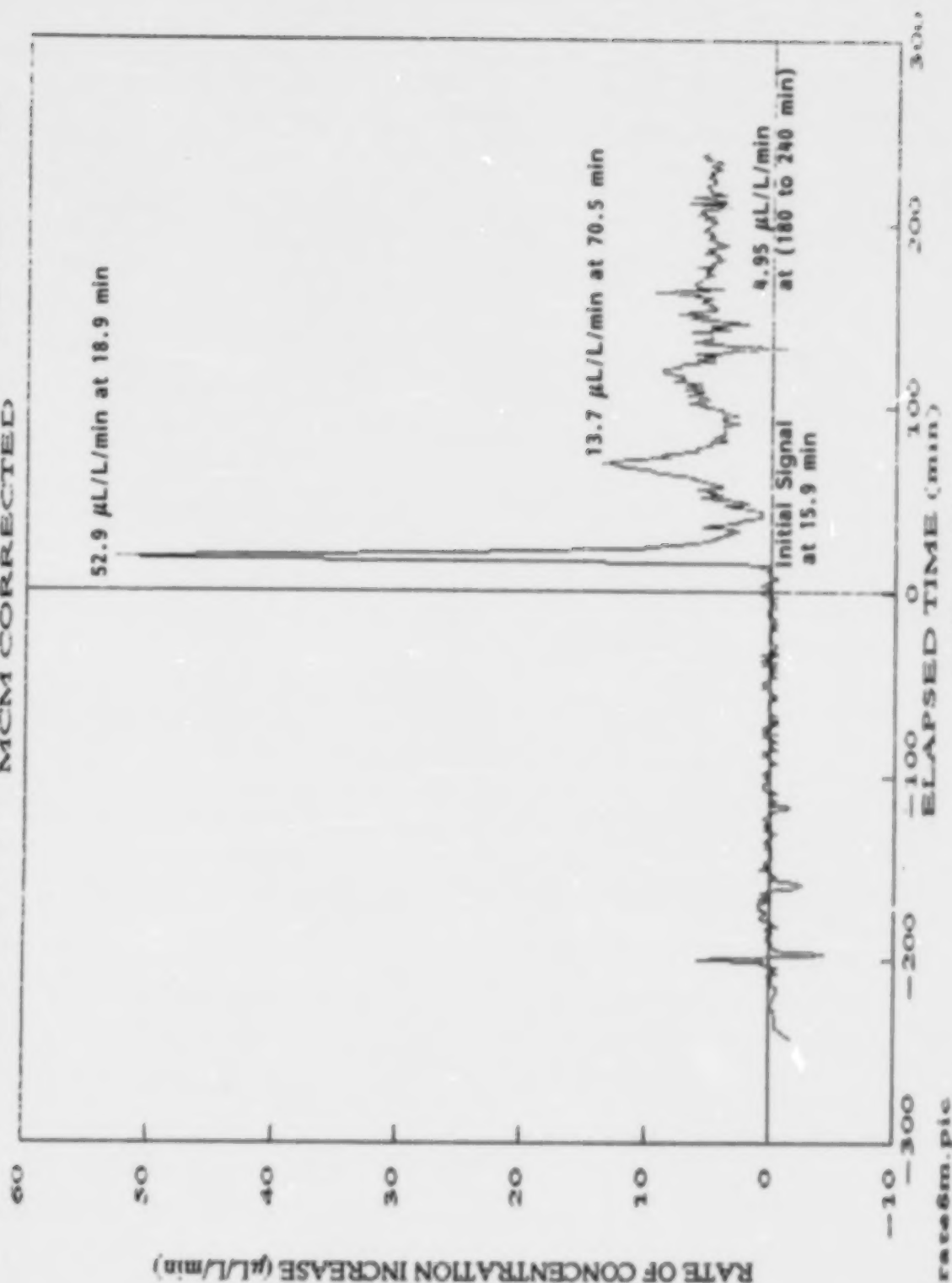


FIGURE E-8(b)

CONCENTRATION INCREASE RATE VS TIME
(CORRECTED FOR BACKGROUND AND PRESSURE INCREASE)

DARLINGTON AGS TEST 9

MCM CORRECTED

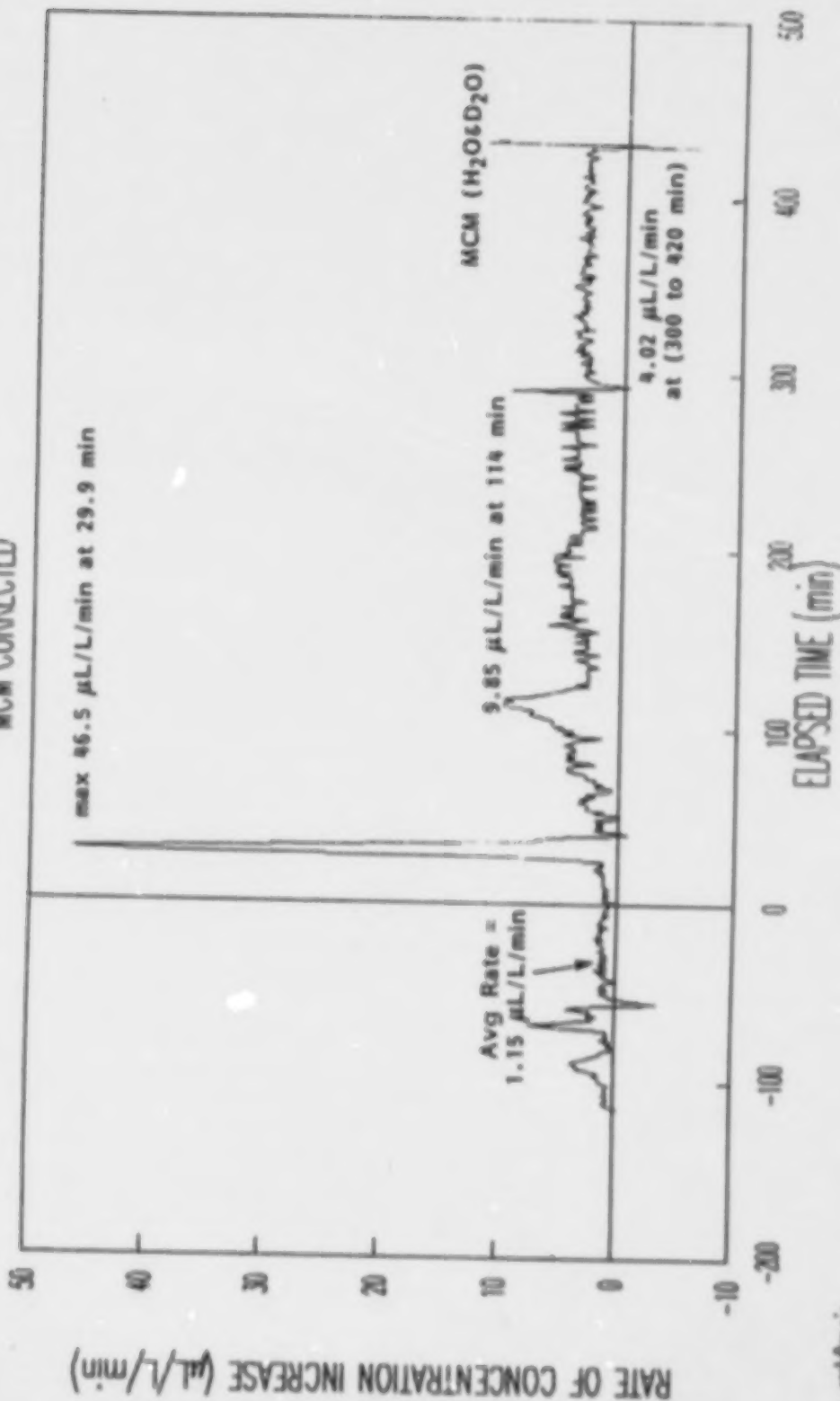


FIGURE E-9(a)

CONCENTRATION INCREASE RATE VS TIME
(UNCORRECTED FOR BACKGROUND AND PRESSURE INCREASE)

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DARLINGTON AGS TEST 9

MCM CORRECTED

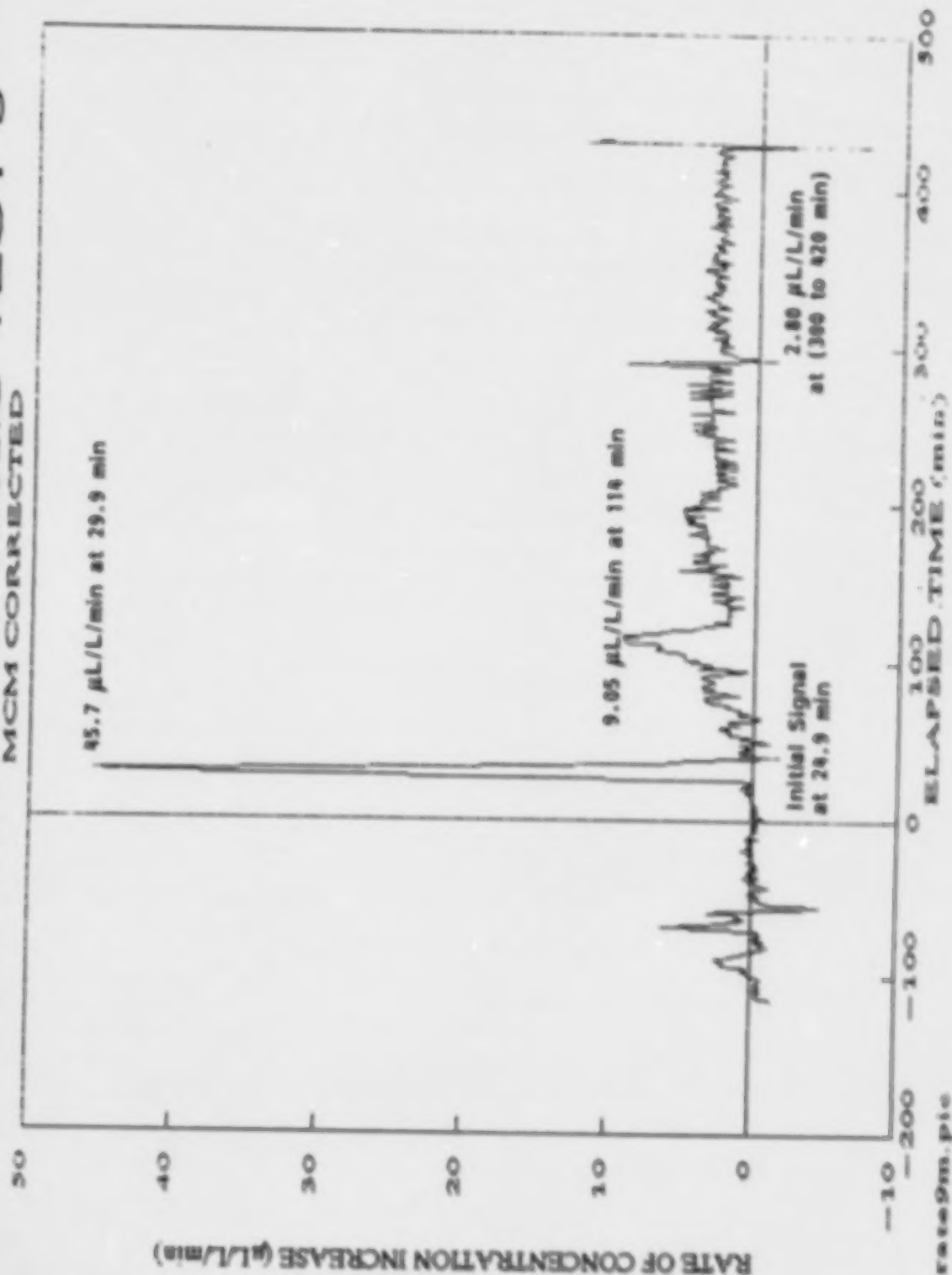


FIGURE E-9(b)
CONCENTRATION INCREASE RATE VS TIME
(CORRECTED FOR BACKGROUND AND PRESSURE INCREASE)

DARLINGTON AGS TEST 10

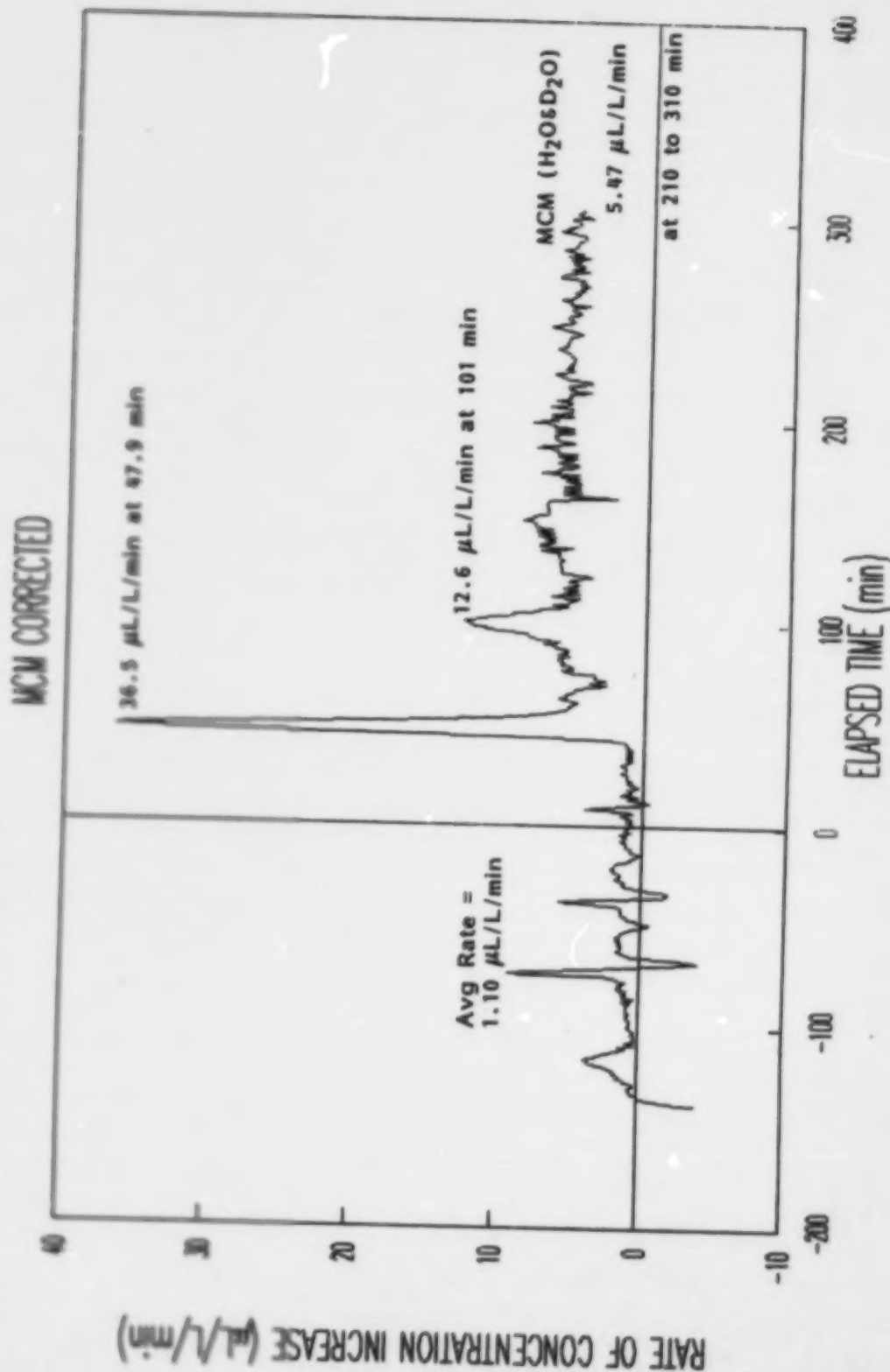


FIGURE E-10(a)
CONCENTRATION INCREASE RATE VS TIME
(UNCORRECTED FOR BACKGROUND AND PRESSURE INCREASE)

DARLINGTON AGS TEST 10

MCM CORRECTED

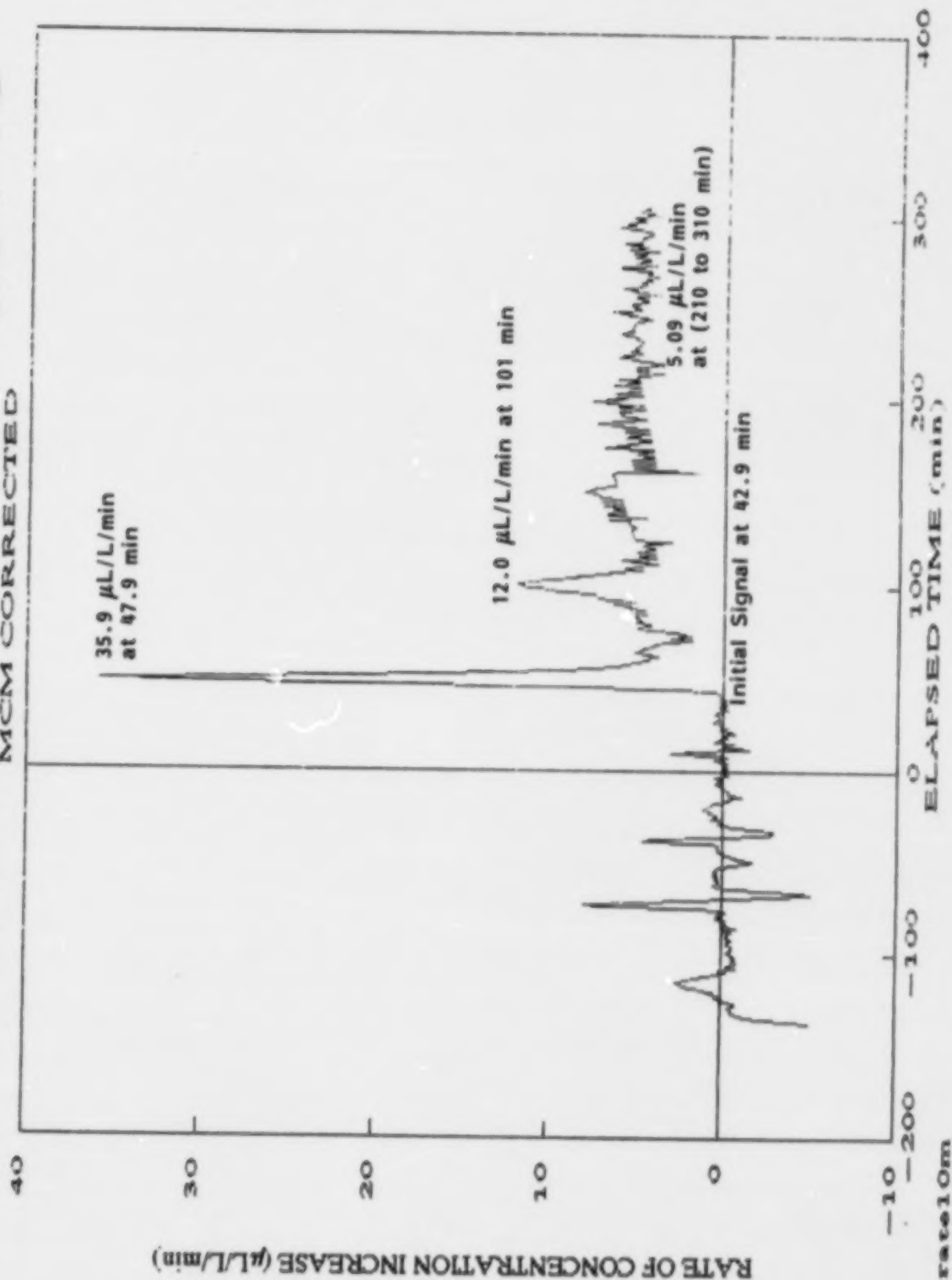


FIGURE E-10(b)
CONCENTRATION INCREASE RATE VS TIME
(CORRECTED FOR BACKGROUND AND PRESSURE INCREASE)

DARLINGTON AGS TEST 13

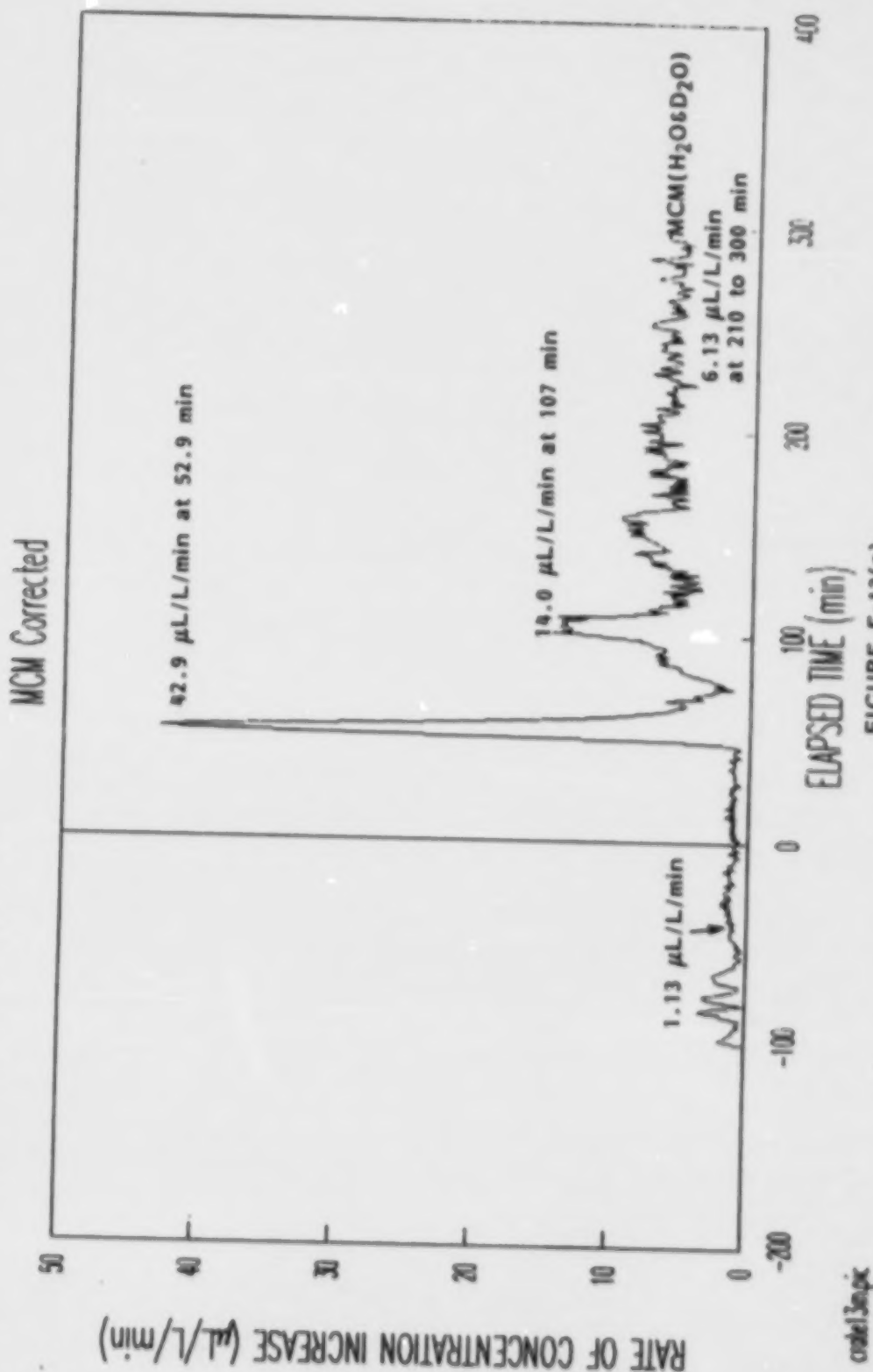


FIGURE E-13(a)
CONCENTRATION INCREASE RATE VS TIME
(UNCORRECTED FOR BACKGROUND AND PRESSURE INCREASE)

DARLINGTON AGS TEST 13

MCM Corrected

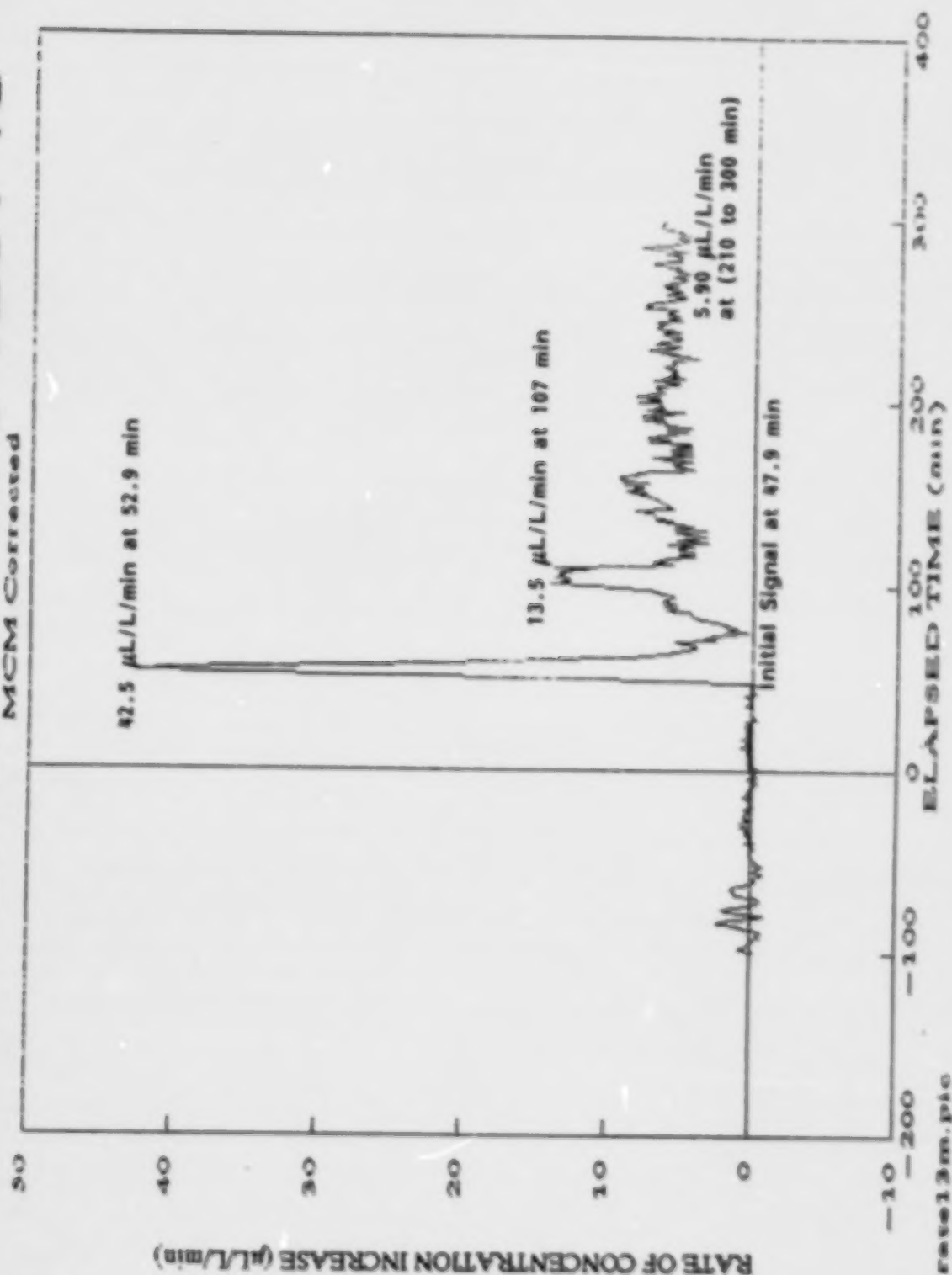


FIGURE E-13(b)
CONCENTRATION INCREASE RATE VS TIME
(CORRECTED FOR BACKGROUND AND PRESSURE INCREASE)

DARLINGTON AGS TEST 14

MCM Corrected

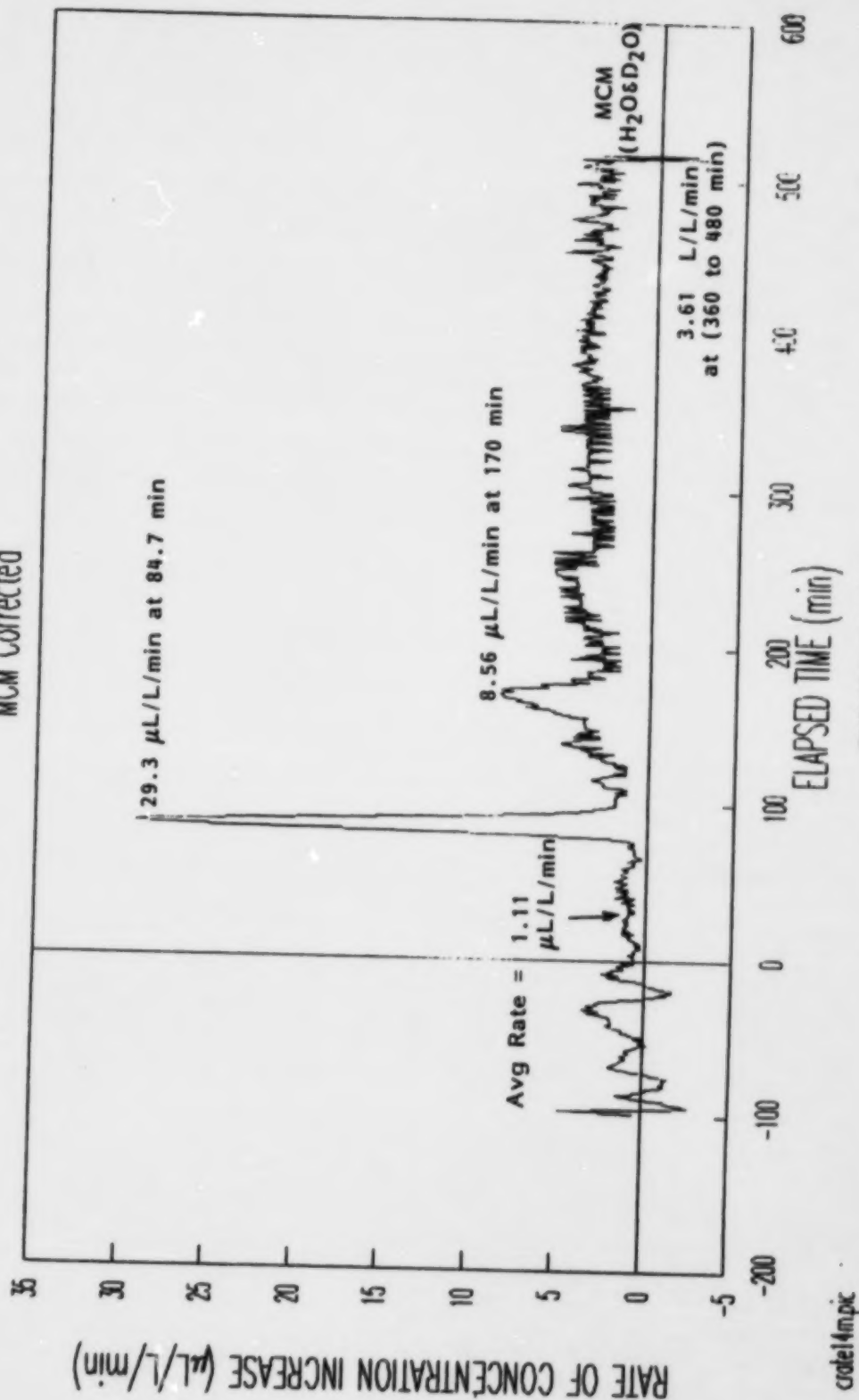


FIGURE E-14(a)

CONCENTRATION INCREASE RATE VS TIME
(UNCORRECTED FOR BACKGROUND AND PRESSURE INCREASE)

DARLINGTON AGS TEST 14

MCM Corrected

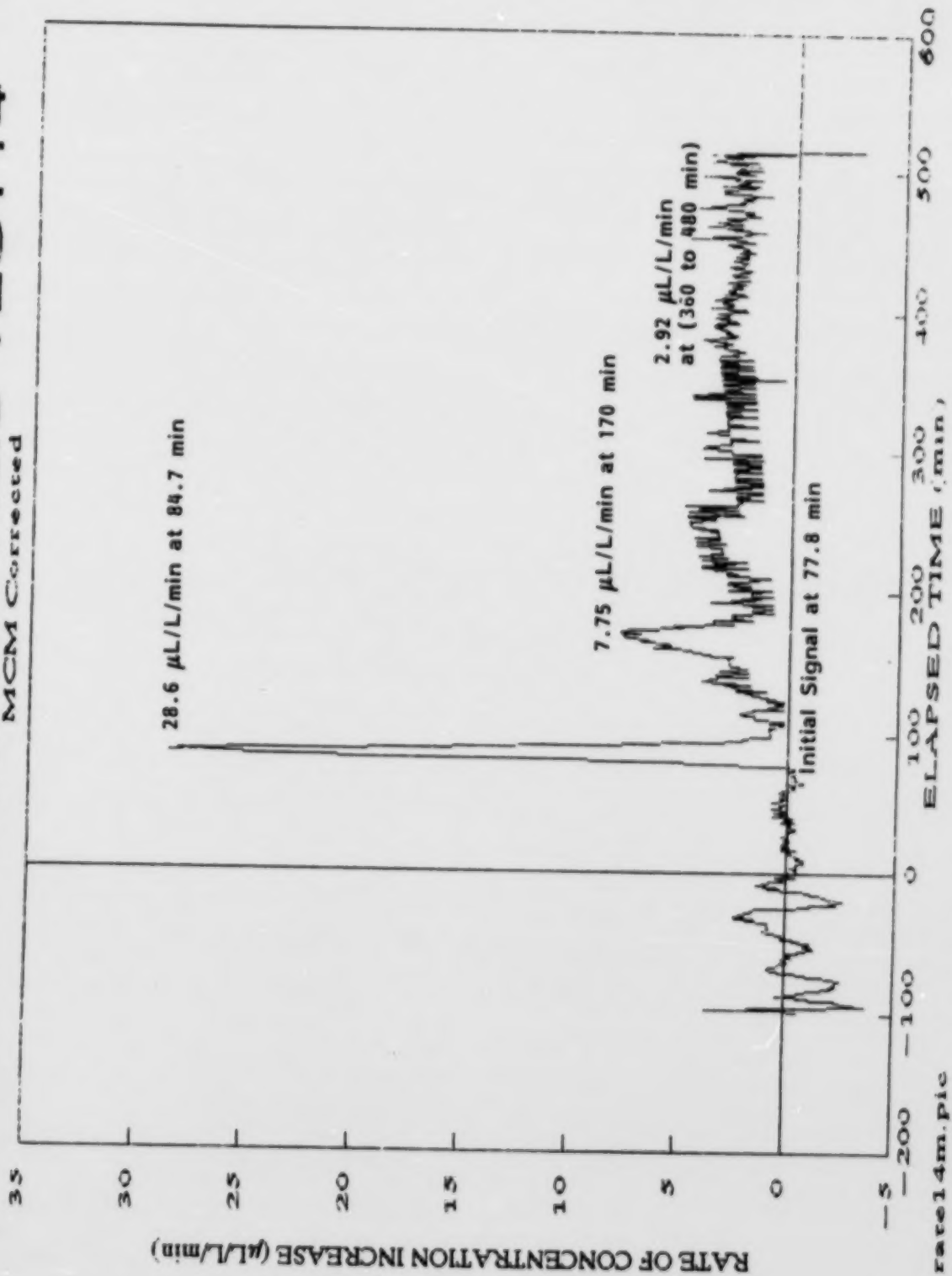


FIGURE E-14(b)

CONCENTRATION INCREASE RATE VS TIME (CORRECTED FOR BACKGROUND AND PRESSURE INCREASE)

DARLINGTON AGS TEST 15

MCM Corrected

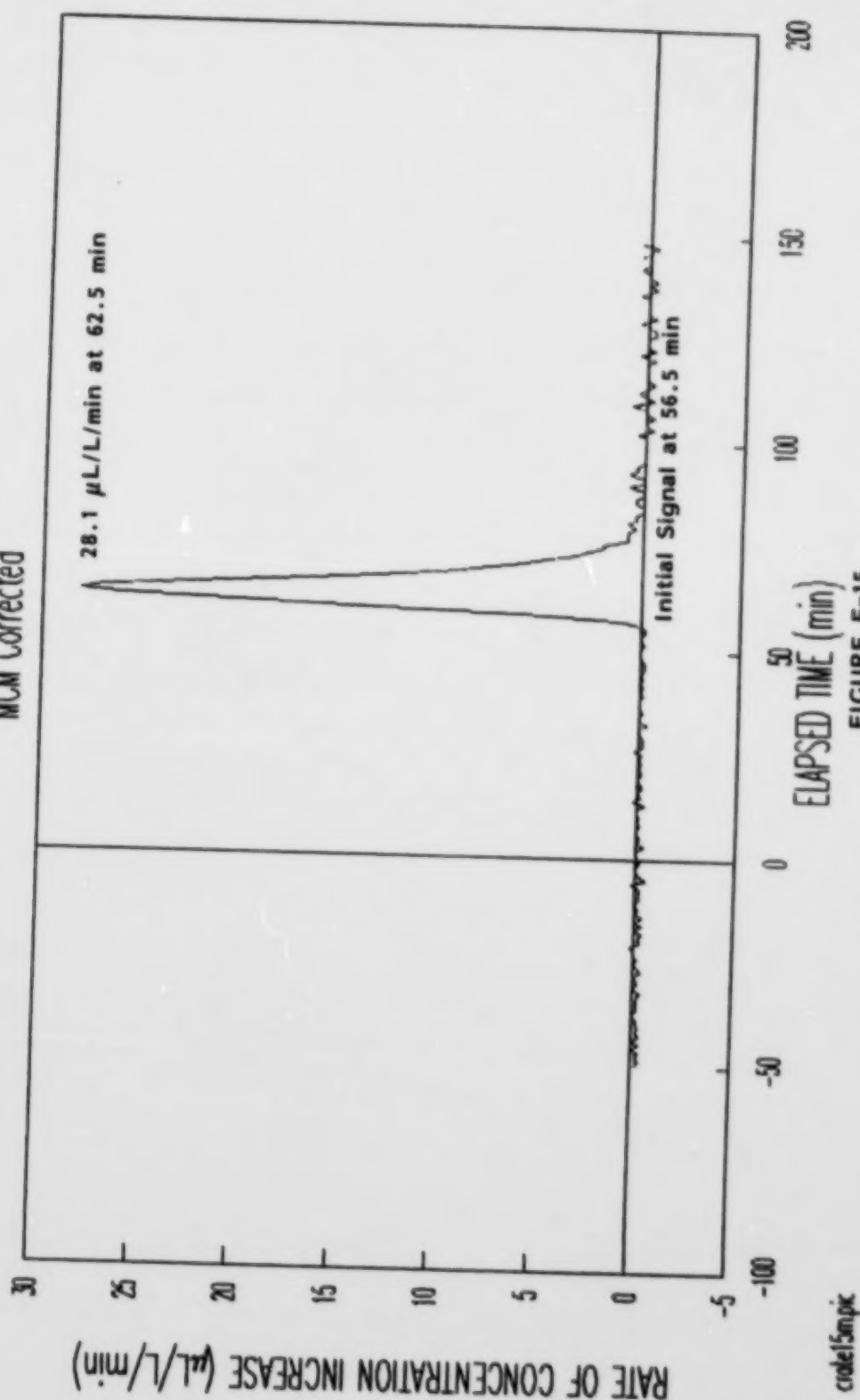
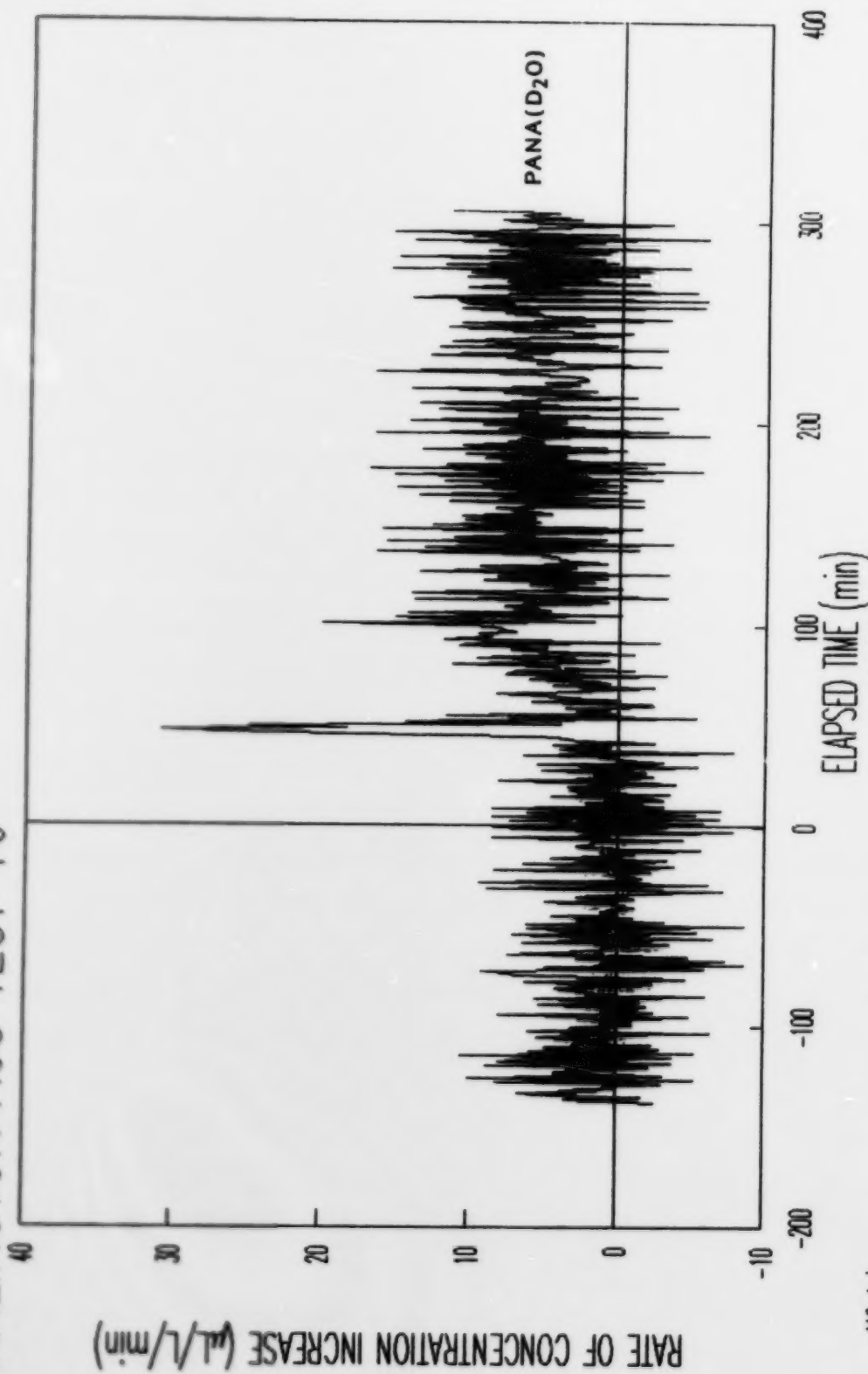


FIGURE E-15
CONCENTRATION INCREASE RATE VS TIME
(CORRECTION FOR BACKGROUND AND PRESSURE INCREASE UNNECESSARY)

DARLINGTON AGS TEST 10

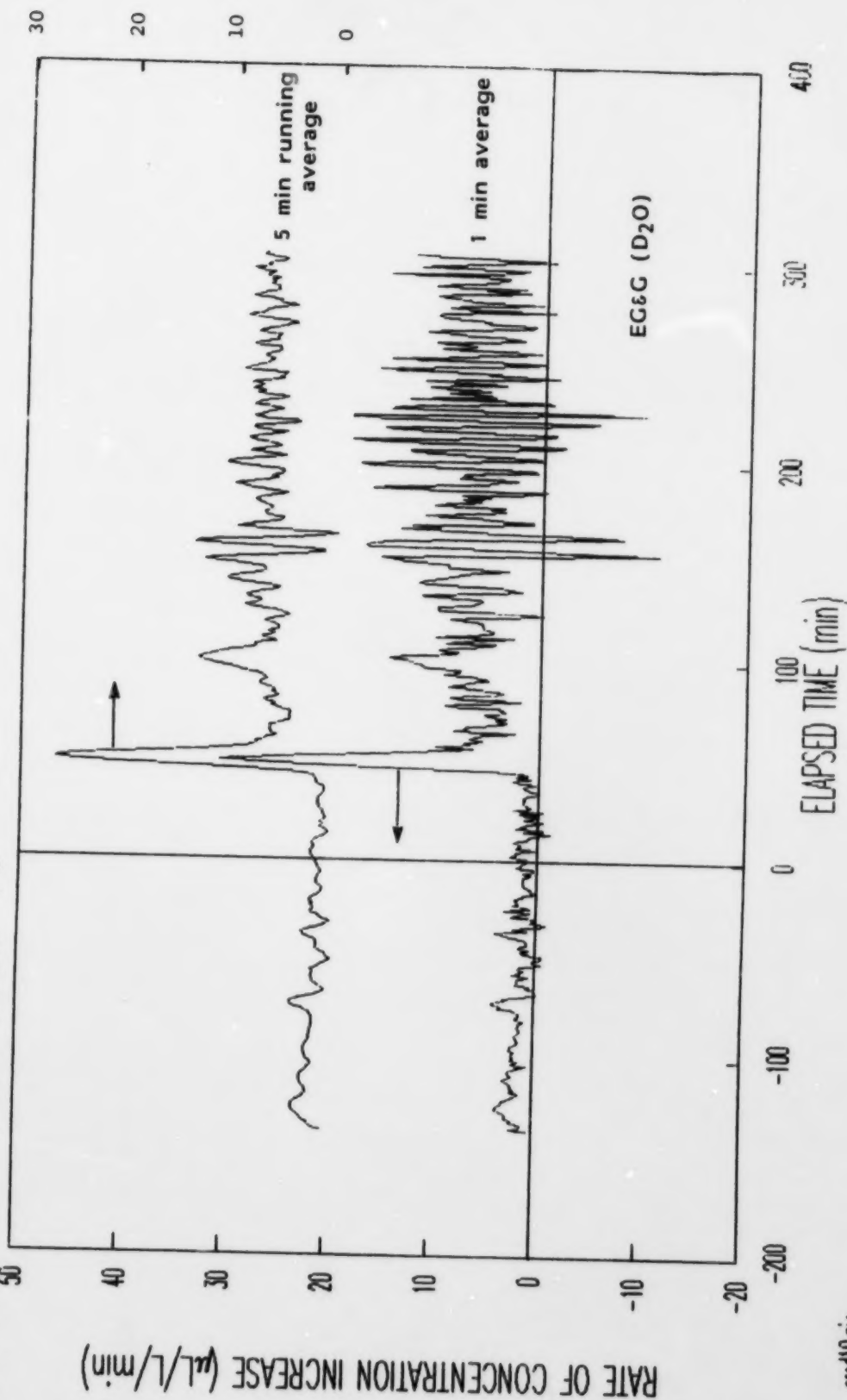


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FIGURE E-16

NOISY RESPONSE OF PANAMETRICS DUE TO IMPROPER SIGNAL TAKE-OFF

DARLINGTON AGS TEST 10



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FIGURE E-17

THE EG&G RESPONSE WAS SIGNIFICANTLY MORE NOISY THAN THE MCM RESPONSE

APPENDIX F

PLUG FLOW AGS RESPONSE

It is possible to carry out a plug flow response of the AGS for a cold reactor since the gas linear velocity remains constant in the annuli and does not increase to an unknown value as in a hot reactor. Typical results which require only minutes to be computed by the MODL1 program given below are shown in Figure F.1 for times up to 255 minutes. Figure F.1 shows the step changes as the individual streams exit the 4,7,8,9,10,11, and 12 channel strings with the large effect of the twenty twelve channel strings on the overall response.

Figures F.2 and F.3 show the actual response data and the calculated responses assuming plug flow and perfect mixing. It is expected that the actual response would be in between the two extremes assuming no adsorption resulting in signal delay.

Figure F.4 shows that for the same leak rate, the initial signal for single compressor operation, i.e., lower flow rate is larger than that for two compressor operation but occurs later.

Figure F.5 shows that the concentration increases approximately linearly after the initial period of large step changes with condensation expected in the leaking string after 7.5 h at a 5g/h leak rate. The MODL2 program given below was used to generate the data for times greater than 255 minutes.

Figure F.6 shows the result of assuming a fully developed velocity profile in the annulus and dividing the test channel into five subchannels of equal flow rate but unequal area and allowing mixing after each channel in an attempt to smooth out the plug flow response. The signal appears earlier and the initial slope is still poorly modelled (MODL4).

The following relates to the generation of Figure F.6. From Bird, Stewart and Lightfoot, Transport Phenomena, pg 51, the velocity at any radius in the annulus is given by:

$$v = (\Delta P R^2) / (4 \mu L) * [1 - (r/R)^2 + (1 - K^2) / \ln(1/K) * \ln(r/R)]$$

where R is the outer radius and KR the inner radius.

The average velocity is given by:

$$v_{avg} = (\Delta P R^2) / (8 \mu L) * [(1 - K^4) / (1 - K^2) - (1 - K^2) / \ln(1/K)]$$

After substituting the above expressions for v and the pressure drop, we can integrate $2\pi r v dr$ between KR and R to find the flow rate through the subchannel.

The AGSK5.BAS program was used to calculate the radii of the five annuli through which the flows were equal.

```

10 REM *****DESCRIPTION OF THIS PROGRAM*****
20 REM *****MODL1T5.BAS*****
30 REM *****THIS IS A PURE PLUG FLOW MODEL*****
40 REM *****IT INCLUDES A PERFECT MIXING/CONTINUOUS STIRRED TANK REACTOR
    ESTIMATE*****
50 OPEN"O",#1,"MODL1T5.PRN"
60 REM *****INITIAL VALUES*****
70 REM *****NUMBER OF CHANNELS IN STRING AND CHANNEL VOLUME, LITRES*****
80 N4=4:N7=4:N8=4:N9=4:N10=4:N11=8:N12=20:CHVOL=31.5
90 REM *****INJECTION RATE (G/HR) AND INITIAL CONCENTRATION (L/L)*****
100 INJRAT =5.05
110 INITCONC=199/1000000:REM PUT IN TERMS OF RATIO OF D2O TO CO2
    :INITCONC=INITCONC/(1-INITCONC)
120 REM *****AVG STRING INLET/OUTLET PRESSURE (kPaG) AND TEMPERATURE (C)****
130 PAVG=(44+22.5)/2:PAVG =PAVG+101.3
140 TAVG=30 :TAVG =273.2+TAVG
150 REM *****FLOWS (L/MIN)*****
160 INJFLOW =3.8:INJFLOW =INJFLOW*(TAVG/298.2)*(101.3/PAVG)
170 TSTCHFLOW=3.75:TSTCHFLOW=TSTCHFLOW*(101.3/PAVG)*(TAVG/313.2)
180 CHFLOW=6.9:CHFLOW=CHFLOW*(101.3/PAVG)*(TAVG/313.2)
190 REM *****DEFINE TEST CHANNEL AND ITS RETENTION TIME (MIN)*****
200 CHINTSTSTRING=12
210 RTTSTX = CHINTSTSTRING*CHVOL/(TSTCHFLOW+INJFLOW)
220 REM *****REDUCE NUMBER OF STRINGS OF TEST CHANNEL LENGTH BY ONE****
230 N12=N12-1
240 REM*****END OF INITIAL VALUES*****
250 REM *****RETENTION TIMES OF OTHER CHANNELS (MIN)*****
260 RT4X = 4*CHVOL/CHFLOW
270 RT7X = 7*CHVOL/CHFLOW
280 RT8X = 8*CHVOL/CHFLOW
290 RT9X = 9*CHVOL/CHFLOW
300 RT10X =10*CHVOL/CHFLOW
310 RT11X =11*CHVOL/CHFLOW
320 RT12X =12*CHVOL/CHFLOW
330 REM*****
340 REM*****

```

```

350 REM*****PROGRAM*****
360 REM **C40=4 CHANNEL STRING OUTLET CONC**CI=ALL CHANNEL INLET CONC*****
370 DIM C40(255),C70(255),C80(255),C90(255),C100(255),C110(255),C120(255),
    CI(255)
380 DIM CTSTO(255)
390 CI(0)=INITCONC
400 REM *****
410 FOR T=0 TO RTTSTX:CTSTO(T)=CI(0):NEXT
420 FOR T=0 TO RT4X :C40(T) =CI(0):NEXT
430 FOR T=0 TO RT7X :C70(T) =CI(0):NEXT
440 FOR T=0 TO RT8X :C80(T) =CI(0):NEXT
450 FOR T=0 TO RT9X :C90(T) =CI(0):NEXT
460 FOR T=0 TO RT10X :C100(T) =CI(0):NEXT
470 FOR T=0 TO RT11X :C110(T) =CI(0):NEXT
480 FOR T=0 TO RT12X :C120(T) =CI(0):NEXT
490 REM *****
500 INJFLOWCONC=INJRAT/20*22.4/60*(101.325/PAVG)*(TAVG/273.2)
    :INJFLOWCONC=INJFLOWCONC/INJFLOW:REM PRINT INJFLOWCONC
510 T=0
520 CI(T)=((W4*C40(T)+W7*C70(T)+W8*C80(T)+W9*C90(T)+W10*C100(T)+W11*C110(T)+W12
    *C120(T))*CHFLOW+CTSTO(T)*(TSTCHFLOW+INJFLOW))/(.47*CHFLOW+TSTCHFLOW+INJFLOW)
530 IF (T+RTTSTX)>255 THEN 550
540 CTSTO(T+RTTSTX)=(CI(T)*TSTCHFLOW+INJRAT/20*22.4/60*101.325/PAVG*TAVG/273.2)/
    (INJFLOW+TSTCHFLOW)
550 IF (T+RT4X)>255 THEN 570
560 C40(T+RT4X) =CI(T)
570 IF (T+RT7X)>255 THEN 590
580 C70(T+RT7X) =CI(T)
590 IF (T+RT8X)>255 THEN 610
600 C80(T+RT8X) =CI(T)
610 IF (T+RT9X)>255 THEN 630
620 C90(T+RT9X) =CI(T)
630 IF (T+RT10X)>255 THEN 650
640 C100(T+RT10X) =CI(T)
650 IF (T+RT11X)>255 THEN 670
660 C110(T+RT11X) =CI(T)
670 IF (T+RT12X)>255 THEN 690
680 C120(T+RT12X) =CI(T)
690 REM *****RECALCULATE CONC IN MICROLITRE O2O/L (O2O+CO2)*****
700 OUTLET=CI(T)/(1+CI(T))*1000000
710 REM *****CHECK FOR CONDENSATION IN THE TEST CHANNEL*****
720 CTSTCH=CTSTO(T)/(1+CTSTO(T))*1000000:PD20=CTSTCH/1000000*PAVG*1000
730 PRINT T,OUTLET,CTSTCH,PD20
740 IF PD20>2000 THEN PRINT "CONDENSATION WILL OCCUR IN THE TEST CHANNEL IF THE
    TEMPERATURE DROPS BELOW 20 DEG C"
750 REM LPRINT T,CI(T),CTSTO(T)
760 PRINT#1,T,OUTLET
770 T=T+1:IF T<256 THEN 520
780 REM*****CSTR ESTIMATE*****
790 CSTRCONC255=255*INJRAT/20*22.4/60*101.325/PAVG*TAVG/273.2*1000000/(CHVOL*4
    80)+1000000*INITCONC/(1+INITCONC)
800 PRINT 255,CSTRCONC255
810 PRINT#1,255,CSTRCONC255
820 CLOSE#1
830 STOP

```

DARLINGTON AGS TESTS

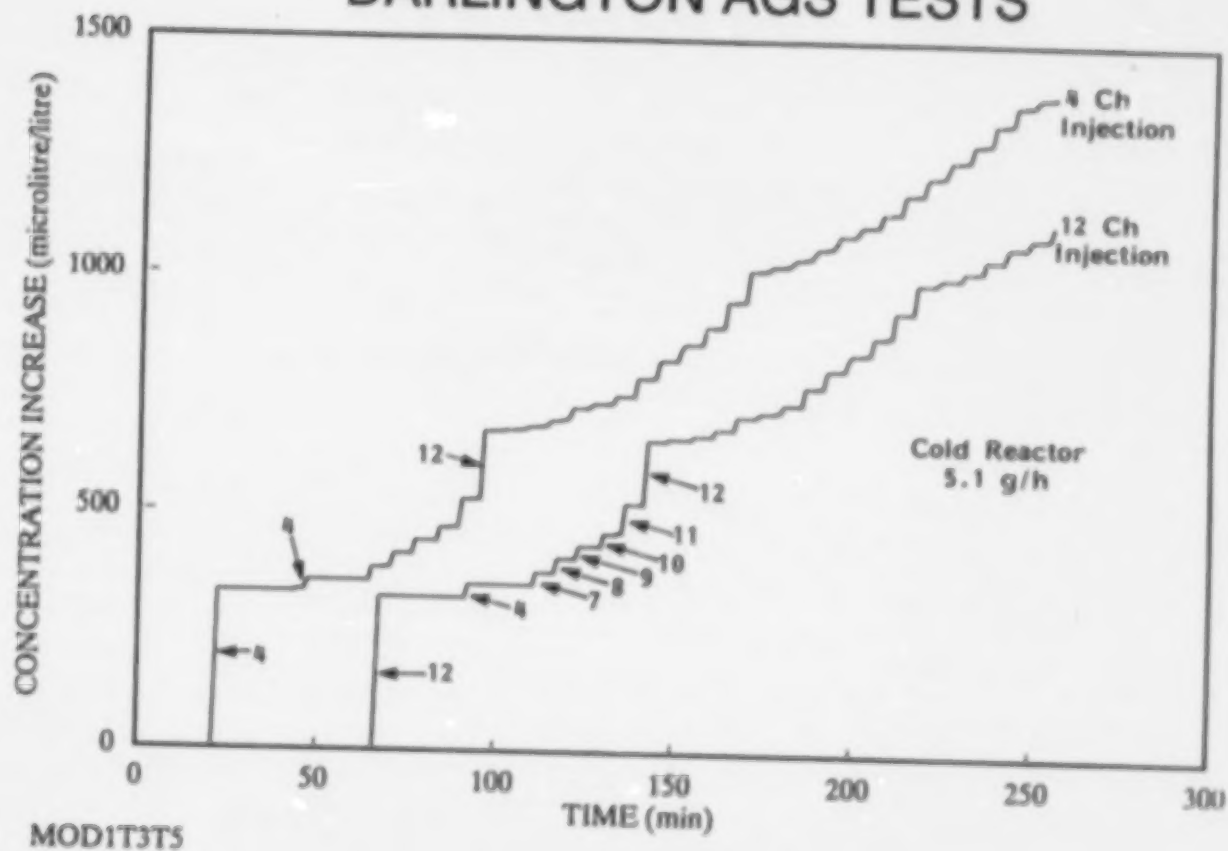


FIGURE F-1

STEP INCREASES IN CONCENTRATION OCCUR WITH EACH DISCHARGE FROM THE STRINGS OF DIFFERENT LENGTHS (PLUG FLOW ASSUMED)

DARLINGTON AGS TESTS

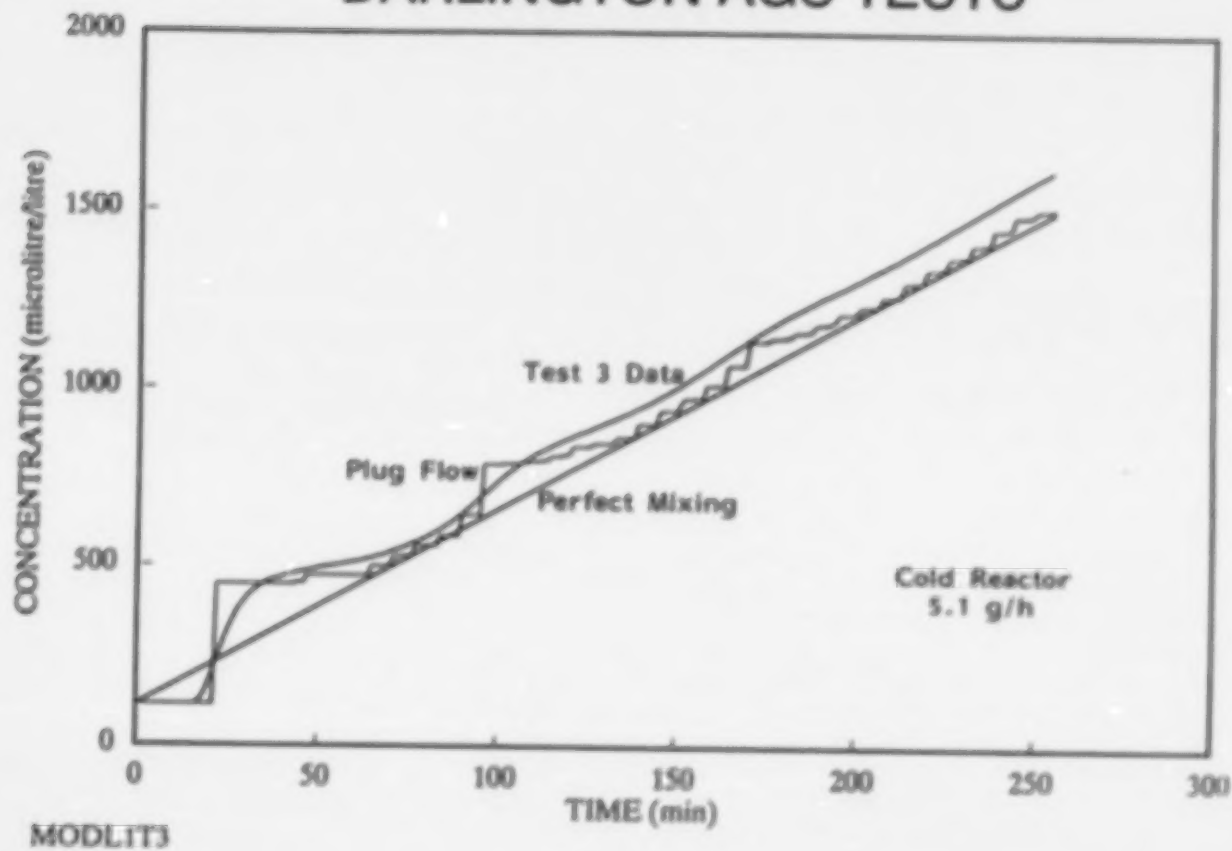


FIGURE F-2
COMPARISON OF TEST DATA WITH THEORETICAL ESTIMATES
OF FOUR CHANNEL STRING RESPONSE

DARLINGTON AGS TESTS

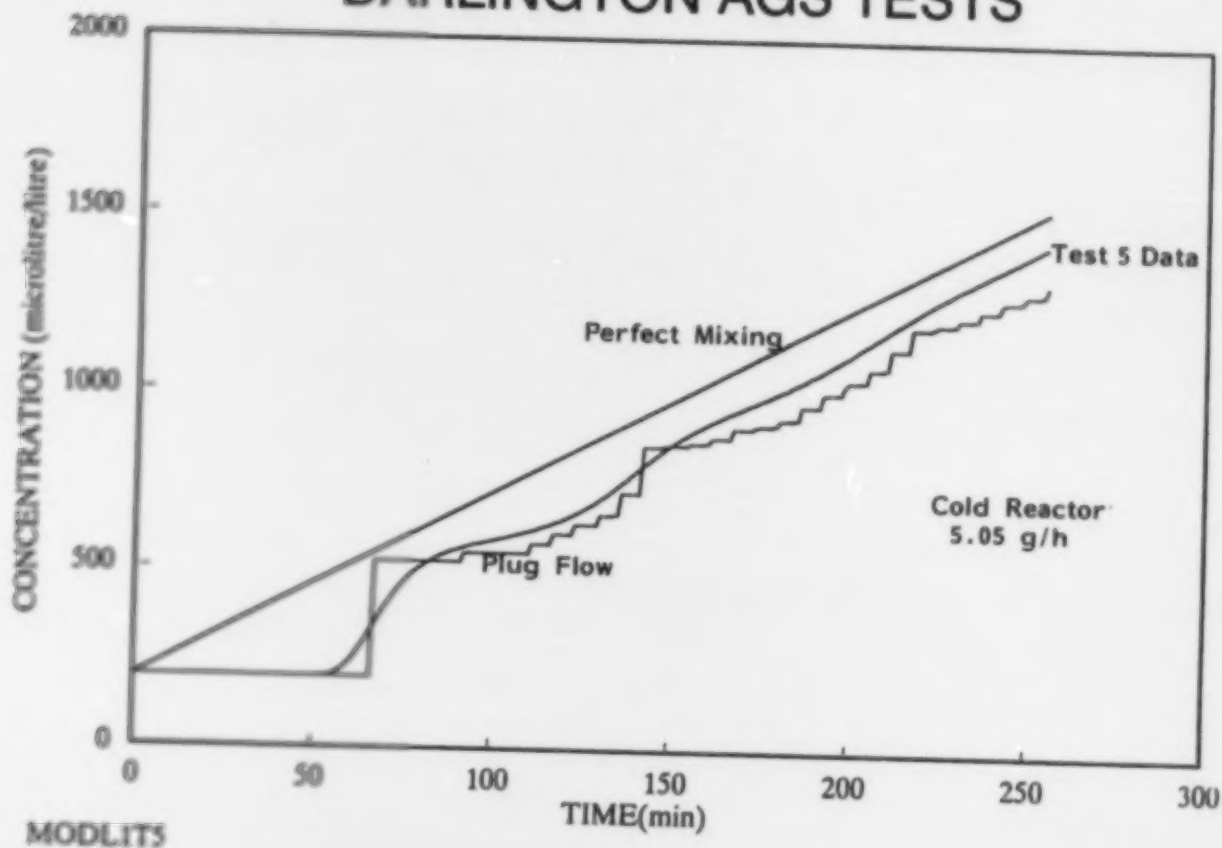


FIGURE F-3
COMPARISON OF TEST DATA WITH THEORETICAL ESTIMATE
OF TWELVE CHANNEL STRING RESPONSE

DARLINGTON AGS TESTS

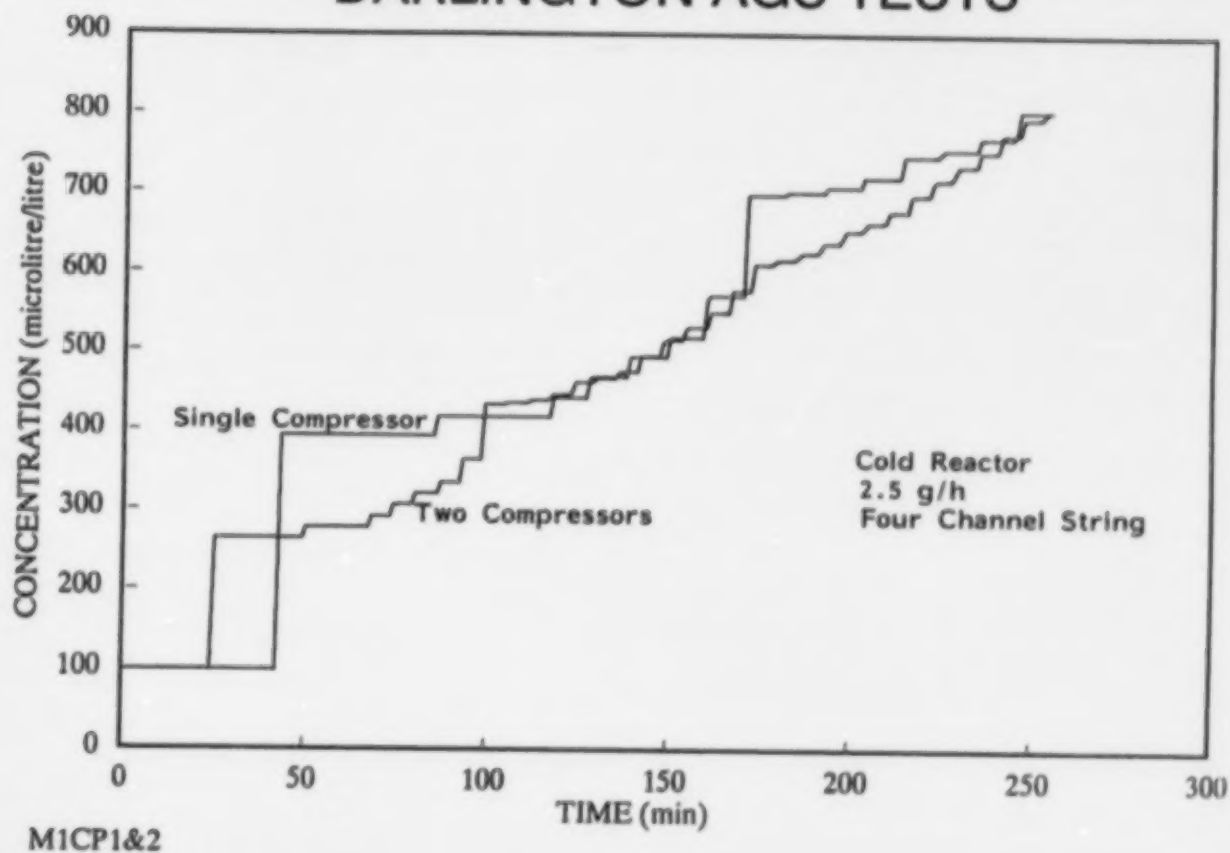


FIGURE F-4
THE SIGNAL IS DELAYED WITH SINGLE COMPRESSOR OPERATION
ALTHOUGH THE STEP CHANGE IS LARGER

```

20 REM *****DESCRIPTION OF THIS PROGRAM*****
20 REM *****MODLZTS.BAS*****
30 REM *****THIS IS A PURE PLUG FLOW MODEL*****
40 REM *****IT INCLUDES A PERFECT MIXING/CONTINUOUS STIRRED TANK REACTOR
    ESTIMATE*****
50 REM *****INITIAL VALUES*****
60 REM *****NUMBER OF CHANNELS IN STRING AND CHANNEL VOLUME, LITRES*****
70 N4=4;N7=4;N8=4;N9=4;N10=4;N11=8;N12=20;CHVOL=31.5
80 REM *****INJECTION RATE (G/HR) AND INITIAL CONCENTRATION (L/L)*****
90 INJRAT =5.05
100 INITCONC=199/1000000;REM PUT IN TERMS OF RATIO OF O2O TO CO2
    :INITCONC=INITCONC/(1-INITCONC)
110 REM *****AVG STPING INLET/OUTLET PRESSURE (kPaG) AND TEMPERATURE (C)****
120 PAVG=(44+22.5)/2;PAVG =PAVG*101.3
130 TAVG=30 ;TAVG =273.2+TAVG
140 REM *****FLOWS (L/MIN)*****
150 INJFLOW =3.8;INJFLOW =INJFLOW*(TAVG/298.2)*(101.3/PAVG)
160 TSTCHFLOW=3.75;TSTCHFLOW=TSTCHFLOW*(101.3/PAVG)*(TAVG/313.2)
170 CHFLOW=6.9;CHFLOW=CHFLOW*(101.3/PAVG)*(TAVG/313.2)
180 REM *****DEFINE TEST CHANNEL AND ITS RETENTION TIME (MIN)*****
190 CHINTSTSTRING=12
200 RTTSTZ = CHINTSTSTRING*CHVOL/(TSTCHFLOW*INJFLOW)
210 REM *****REDUCE NUMBER OF STRINGS OF TEST CHANNEL LENGTH BY ONE****
220 N12=N12-1
230 REM*****END OF INITIAL VALUES*****
240 REM *****RETENTION TIMES OF OTHER CHANNELS (MIN)*****
250 RT4Z = 4*CHVOL/CHFLOW
260 RT7Z = 7*CHVOL/CHFLOW
270 RT8Z = 8*CHVOL/CHFLOW
280 RT9Z = 9*CHVOL/CHFLOW
290 RT10Z =10*CHVOL/CHFLOW
300 RT11Z =11*CHVOL/CHFLOW
310 RT12Z =12*CHVOL/CHFLOW
320 REM*****
330 REM*****
340 REM*****PROGRAM*****

```

```

350 REM **C40=4 CHANNEL STRING OUTLET CONC**C1=ALL CHANNEL INLET CONC*****
360 REM*****NEED FILES FOR C40,C70,C80,C90,C100,C110,C120,CTST0,C1*****
370 REM *****
380 OPEN "R",#1,"CTST0",15 :FIELD#1,5 AS WHENB,10 AS CB
390 T=0:RECHO=1
400 LSET WHENB=MKSB(T):LSET CB=MKSB(INITCONC):PUT #1,RECHO
410 RECHO=RECHO+1:T=T+1:IF T=RTTST% THEN 400
420 CLOSE #1
430 OPEN "R",#1,"C40",15 :FIELD#1,5 AS WHENB,10 AS CB
440 T=0:RECHO=1
450 LSET WHENB=MKSB(T):LSET CB=MKSB(INITCONC):PUT #1,RECHO
460 RECHO=RECHO+1:T=T+1:IF T=RT4% THEN 450
470 CLOSE #1
480 OPEN "R",#1,"C70",15 :FIELD#1,5 AS WHENB,10 AS CB
490 T=0:RECHO=1
500 LSET WHENB=MKSB(T):LSET CB=MKSB(INITCONC):PUT #1,RECHO
510 RECHO=RECHO+1:T=T+1:IF T=RT7% THEN 500
520 CLOSE #1
530 OPEN "R",#1,"C80",15 :FIELD#1,5 AS WHENB,10 AS CB
540 T=0:RECHO=1
550 LSET WHENB=MKSB(T):LSET CB=MKSB(INITCONC):PUT #1,RECHO
560 RECHO=RECHO+1:T=T+1:IF T=RT8% THEN 550
570 CLOSE #1
580 OPEN "R",#1,"C90",15 :FIELD#1,5 AS WHENB,10 AS CB
590 T=0:RECHO=1
600 LSET WHENB=MKSB(T):LSET CB=MKSB(INITCONC):PUT #1,RECHO
610 RECHO=RECHO+1:T=T+1:IF T=RT9% THEN 600
620 CLOSE #1
630 OPEN "R",#1,"C100",15 :FIELD#1,5 AS WHENB,10 AS CB
640 T=0:RECHO=1
650 LSET WHENB=MKSB(T):LSET CB=MKSB(INITCONC):PUT #1,RECHO
660 RECHO=RECHO+1:T=T+1:IF T=RT10% THEN 650
670 CLOSE #1
680 OPEN "R",#1,"C110",15 :FIELD#1,5 AS WHENB,10 AS CB
690 T=0:RECHO=1
700 LSET WHENB=MKSB(T):LSET CB=MKSB(INITCONC):PUT #1,RECHO
710 RECHO=RECHO+1:T=T+1:IF T=RT11% THEN 700
720 CLOSE #1
730 OPEN "R",#1,"C120",15 :FIELD#1,5 AS WHENB,10 AS CB
740 T=0:RECHO=1
750 LSET WHENB=MKSB(T):LSET CB=MKSB(INITCONC):PUT #1,RECHO
760 RECHO=RECHO+1:T=T+1:IF T=RT12% THEN 750
770 CLOSE #1
780 OPEN "R",#1,"C1",15 :FIELD#1,5 AS WHENB,10 AS CB
790 T=0:RECHO=1
800 LSET WHENB=MKSB(T):LSET CB=MKSB(INITCONC):PUT #1,RECHO
810 CLOSE #1

```

```

820 REM *****
830 REM *****FILE FOR STORING THE INLET CONCENTRATION=C*****
840 REM *****CI RESULTS FROM MIXING THE CHANNELS OUTLET COMCS*****
850 OPEN "O",#2,"MODL2T5.PRM"
860 T=0
870 RECNO=T+1
880 OPEN "R",#1,"CTSTO",15 :FIELD#1,5 AS WHEN5,10 AS CS
890 GET #1,RECNO:CTSTO=CVS(CS):CLOSE #1
900 OPEN "R",#1,"C4O",15 :FIELD#1,5 AS WHEN5,10 AS CS
910 GET #1,RECNO:C4O=CVS(CS):CLOSE #1
920 OPEN "R",#1,"C7O",15 :FIELD#1,5 AS WHEN5,10 AS CS
930 GET #1,RECNO:C7O=CVS(CS) :CLOSE #1
940 OPEN "R",#1,"C8O",15 :FIELD#1,5 AS WHEN5,10 AS CS
950 GET #1,RECNO:C8O=CVS(CS):CLOSE #1
960 OPEN "R",#1,"C9O",15 :FIELD#1,5 AS WHEN5,10 AS CS
970 GET #1,RECNO:C9O=CVS(CS):CLOSE #1
980 OPEN "R",#1,"C10O",15 :FIELD#1,5 AS WHEN5,10 AS CS
990 GET #1,RECNO:C10O=CVS(CS):CLOSE #1
1000 OPEN "R",#1,"C11O",15 :FIELD#1,5 AS WHEN5,10 AS CS
1010 GET #1,RECNO:C11O=CVS(CS):CLOSE #1
1020 OPEN "R",#1,"C12O",15 :FIELD#1,5 AS WHEN5,10 AS CS
1030 GET #1,RECNO:C12O=CVS(CS):CLOSE #1
1040 REM *****CALCULATE INLET CONC AT DP METER AT ANY T*****
1050 CI=((N4*C4O+N7*C7O+N8*C8O+N9*C9O+N10*C10O+N11*C11O+N12*C12O)*CHFLOW+CTSTO*
(TSTCHFLOW+INJFLOW))/(47*CHFLOW+TSTCHFLOW+INJFLOW)
1060 REM*****PREDICT TEST STRING EXIT CONC AT T = RTTSTX*****
1070 CTSTO=(CI*TSTCHFLOW+INJRAT/20*22.4/60*101.325/PAVG*TAVG/273.2)/
(INJFLOW+TSTCHFLOW)
1080 OPEN "R",#1,"CTSTO",15:FIELD#1,5 AS WHEN5,10 AS CS:RECNO=T+RTTSTX+1:
LSET WHEN5=MKSS(T+RTTSTX):LSET CS=MKSS(CTSTO):PUT #1,RECNO:CLOSE #1
1090 OPEN "R",#1,"C4O",15:FIELD#1,5 AS WHEN5,10 AS CS:RECNO=T+RT4X+1:
LSET WHEN5=MKSS(T+RT4X):LSET CS=MKSS(CI):PUT #1,RECNO:CLOSE #1
1100 OPEN "R",#1,"C7O",15:FIELD#1,5 AS WHEN5,10 AS CS:RECNO=T+RT7X+1:
LSET WHEN5=MKSS(T+RT7X):LSET CS=MKSS(CI):PUT #1,RECNO:CLOSE #1
1110 OPEN "R",#1,"C8O",15:FIELD#1,5 AS WHEN5,10 AS CS:RECNO=T+RT8X+1:
LSET WHEN5=MKSS(T+RT8X):LSET CS=MKSS(CI):PUT #1,RECNO:CLOSE #1
1120 OPEN "R",#1,"C9O",15:FIELD#1,5 AS WHEN5,10 AS CS:RECNO=T+RT9X+1:
LSET WHEN5=MKSS(T+RT9X):LSET CS=MKSS(CI):PUT #1,RECNO:CLOSE #1
1130 OPEN "R",#1,"C10O",15:FIELD#1,5 AS WHEN5,10 AS CS:RECNO=T+RT10X+1:
LSET WHEN5=MKSS(T+RT10X):LSET CS=MKSS(CI):PUT #1,RECNO:CLOSE #1
1140 OPEN "R",#1,"C11O",15:FIELD#1,5 AS WHEN5,10 AS CS:RECNO=T+RT11X+1:
LSET WHEN5=MKSS(T+RT11X):LSET CS=MKSS(CI):PUT #1,RECNO:CLOSE #1
1150 OPEN "R",#1,"C12O",15:FIELD#1,5 AS WHEN5,10 AS CS:RECNO=T+RT12X+1:
LSET WHEN5=MKSS(T+RT12X):LSET CS=MKSS(CI):PUT #1,RECNO:CLOSE #1
1160 REM *****RECALCULATE CONC IN MICROLITRE D2O/L (D2O+CO2)*****
1170 COUTLET=CI/(1+CI)*1000000
1180 REM *****CHECK FOR CONDENSATION IN THE TEST CHANNEL*****
1190 CTSTCH=CTSTO/(1+CTSTO)*1000000:PD2O=CTSTCH/1000000*PAVG*1000
1200 PRINT T,COUTLET,CTSTCH,PD2O
1210 PRINT#2,T,COUTLET
1220 IF PD2O>2000 THEN PRINT "CONDENSATION WILL OCCUR IN THE TEST CHANNEL IF THE
TEMPERATURE DROPS BELOW 20 DEG C":IF PD2O>2000 THEN 1240
1230 T=T+1:GOTO 870
1240 REM*****CSTR ESTIMATE*****
1250 CSTRCONC255=255*INJRAT/20*22.4/60*101.325/PAVG*TAVG/273.2*1000000/(CHVOL*
480)+1000000*INITCONC/(1+INITCONC)
1260 PRINT 255,CSTRCONC255
1270 PRINT#2,255,CSTRCONC255
1280 CLOSE#2
1290 STOP

```

DARLINGTON AGS TESTS

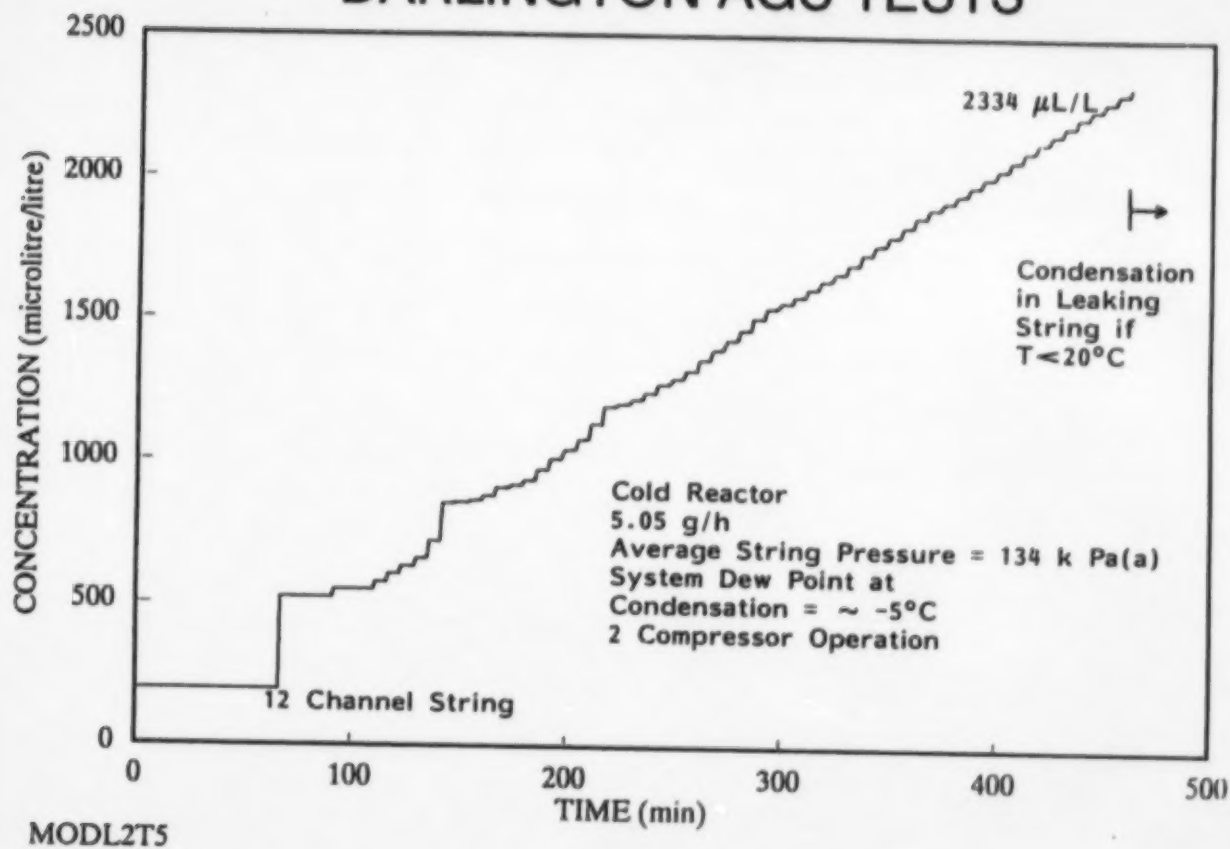


FIGURE F-5
CONDENSATION OCCURS IN LEAKING STRING AFTER ABOUT 7.5h

```

10 REM **AGSK5.BAS;**CALCULATES K'S FOR 5 SUBCHANNELS OF EQUAL FLOWS*****
20 REM **CALCULATES RETENTION TIME DISTRIBUTION*****
30 REM ***** INITIAL VALUES*****UNITS IN METRES*****
40 DIM K(21)
50 K(0)=111.8/129:R=129/2000:I=1
60 K(1)=K(0)+21/129      :REM THIS IS A GUESS FOR K(1)
70 REM *****PROGRAM*****
80 REM *****FLOW THROUGH AREA FROM K1R TO KR*****
90 STORE1=(4*3.141592654#*(1-K(0)^2))/(R^2*((1-K(0)^4)*LOG(1/K(0))-(1-K(0)^2)^2)
)
100 STORE2=R^2*LOG(1/K(0))*(.5*(K(1)*R)^2-.5*(K(0)*R)^2)
110 STORE3=-LOG(1/K(0))*(1/4*(K(1)*R)^4-1/4*(K(0)*R)^4)
120 STORE4= R^2*(1-K(0)^2)*((K(1)*R)^2/2*LOG(K(1))-(K(1)*R)^2/4-(K(0)*R)^2/2*LOG
(K(0))+K(0)*R)^2/4)
130 CALCFLOW = STORE1*(STORE2+STORE3+STORE4)
140 REM **DIFFERENCE BETWEEN CALCULATED FLOW AND DESIRED FLOW (SUBCHFLOW)*****
150 SUBCHFLOW=1/5*3.141592654#*(R)^2-(R*K(0))^2)
160 IF (CALCFLOW+.000001)>=SUBCHFLOW THEN 230
170 PRINT CALCFLOW-SUBCHFLOW,K(1)*129,"coarse search"
180 REM
190 K(1)=K(1)+.0001
200 GOTO 100
210 REM*****
220 REM SEARCH IN SMALLER STEPS
230 K(1)=K(1)-.0001
240 K(1)=K(1)+.000001
250 STORE1=(4*3.141592654#*(1-K(0)^2))/(R^2*((1-K(0)^4)*LOG(1/K(0))-(1-K(0)^2)^2
))
260 STORE2=R^2*LOG(1/K(0))*(.5*(K(1)*R)^2-.5*(K(0)*R)^2)
270 STORE3=-LOG(1/K(0))*(1/4*(K(1)*R)^4-1/4*(K(0)*R)^4)
280 STORE4= R^2*(1-K(0)^2)*((K(1)*R)^2/2*LOG(K(1))-(K(1)*R)^2/4-(K(0)*R)^2/2*LOG
(K(0))+K(0)*R)^2/4)
290 CALCFLOW = STORE1*(STORE2+STORE3+STORE4)
300 PRINT CALCFLOW-SUBCHFLOW,K(1)*129,"fine search"
310 IF CALCFLOW>=SUBCHFLOW THEN 330
320 GOTO 240
330 LPRINT K(1),K(1)*129,(CALCFLOW-SUBCHFLOW)/SUBCHFLOW*100
340 REM
350 REM *****CALCULATE NEXT K(I)*****
360 I = I+1
370 IF I>5 THEN 410
380 K(1)=K(I-1)
390 GOTO 100

```

```

400 REM *****CALCULATE RANGE OF RETENTION TIMES*****
410 CHVOL = 31.5
420 SUBCHFLOW=6.8/5
430 L=CHVOL*1000/((22/7*(129*129-111.8*111.8)/4)
440 R=129/2
450 FOR I =0 TO 4
460 SUBCHVOL=22/7*(K(I+1)*K(I+1)*R*R-K(I)*K(I)*R*R)*L/1000
470 RT=SUBCHVOL/SUBCHFLOW:RTX=RT:TWICERTX=RT*2:FOURRTX=4*RT
480 RT=SUBCHVOL/SUBCHFLOW:RTX=RT:TWICERTX=RT*2:FOURRTX=4*RT
490 LPRINT "SUBCHAN=";I+1;"RT=";RT;RTX;TWICERTX;FOURRTX
500 NEXT

```

.9056109	116.8238	9.304836E-03
.925178	119.348	1.288362E-03
.9430549	121.6541	2.010083E-03
.9623493	124.1431	1.046794E-03
.9995866	128.9467	2.891657E-03
SUBCHAN= 1 RT= 6.42304 6 13 26		
SUBCHAN= 2 RT= 3.33373 3 7 13		
SUBCHAN= 3 RT= 3.108063 3 6 12		
SUBCHAN= 4 RT= 3.421246 3 7 14		
SUBCHAN= 5 RT= 6.798753 7 14 27		

```

10 REM *****DESCRIPTION OF THIS PROGRAM*****
20 REM *****MODL4T3.BAS*****
30 REM *****THIS IS A PLUG FLOW MODEL IT USES 5 SUBCHANNELS WITH MIXING AFTER
    EACH CHANNEL*****
40 REM *****IT INCLUDES A PERFECT MIXING/CONTINUOUS STIRRED TANK REACTOR
    ESTIMATE*****
50 REM *****INITIAL VALUES*****
60 K0=111.8/129
70 K1=.9056109
80 K2=.925178
90 K3=.9430549
100 K4=.9623493
110 K5=1
120 REM *****NUMBER OF CHANNELS IN STRING *****
130 N4=4:N7=4:N8=4:N9=4:N10=4:N11=8:N12=20
140 REM *****CHANNEL DIMENSIONS***CHVOL IN LITRES*****
150 CHVOL=31.5: R=12.9/2:L=22/7*(12.9*12.9-11.18*11.18)/4:L=CHVOL*1000/L
160 REM *****INJECTION RATE (G/HR) AND INITIAL CONCENTRATION (L/L)*****
170 INJRAT =5.1
180 INITCONC=116/1000000:REM PUT IN TERMS OF RATIO OF D2O TO CO2
    :INITCONC=INITCONC/(1-INITCONC)
190 REM *****AVG STRING INLET/OUTLET PRESSURE (kPaG) AND TEMPERATURE (C)****
200 PAVG=(36+221)/2:PAVG =PAVG+101.3
210 TAVG=30 :TAVG =273.2+TAVG
220 REM *****FLOWS (L/MIN)*****
230 INJFLOW =3.8:INJFLOW =INJFLOW*(TAVG/298.2)*(101.3/PAVG)
240 TSTCHFLOW=3.7:TSTCHFLOW=TSTCHFLOW*(101.3/PAVG)*(TAVG/313.2)
250 CHFLOW=6.8:CHFLOW=CHFLOW*(101.3/PAVG)*(TAVG/313.2)
260 REM *****DEFINE TEST CHANNEL AND ITS RETENTION TIME (TENTHS OF A MIN)***
270 CHINTSTSTRING=4 :REM *****RT IS FOR ONE CHANNEL NOT THE WHOLE STRING LENGTH
280 RTTSTAX = 10*L*22/7*R/R/1000*(K1*K1-K0*K0)/((TSTCHFLOW+INJFLOW)/5)
290 RTTSTBX = 10*L*22/7*R/R/1000*(K2*K2-K1*K1)/((TSTCHFLOW+INJFLOW)/5)
300 RTTSTCX = 10*L*22/7*R/R/1000*(K3*K3-K2*K2)/((TSTCHFLOW+INJFLOW)/5)
310 RTTSTDx = 10*L*22/7*R/R/1000*(K4*K4-K3*K3)/((TSTCHFLOW+INJFLOW)/5)
320 RTTSTEX = 10*L*22/7*R/R/1000*(K5*K5-K4*K4)/((TSTCHFLOW+INJFLOW)/5)
330 REM *****NEED TO FIND WHICH IS THE SMALLEST*****
340 PRINT "RTTSTAX=",RTTSTAX
350 PRINT "RTTSTBX=",RTTSTBX
360 PRINT "RTTSTCX=",RTTSTCX
370 PRINT "RTTSTDx=",RTTSTDx
380 PRINT "RTTSTEX=",RTTSTEX
390 REM *****REDUCE NUMBER OF STRINGS OF TEST CHANNEL LENGTH BY ONE****
400 N4=N4-1
410 REM*****END OF INITIAL VALUES*****

```

```

420 REM *****RETENTION TIMES OF OTHER CHANNELS (MIN)*****
430 RT4X  = 4*CHVOL/CHFLOW*10:PRINT "RT4X=",RT4X
440 RT7X  = 7*CHVOL/CHFLOW*10:PRINT "RT7X=",RT7X
450 RT8X  = 8*CHVOL/CHFLOW*10:PRINT "RT8X=",RT8X
460 RT9X  = 9*CHVOL/CHFLOW*10:PRINT "RT9X=",RT9X
470 RT10X =10*CHVOL/CHFLOW*10:PRINT "RT10X=",RT10X
480 RT11X =11*CHVOL/CHFLOW*10:PRINT "RT11X=",RT11X
490 RT12X =12*CHVOL/CHFLOW*10:PRINT "RT12X=",RT12X
500 REM*****
510 REM*****PROGRAM*****
520 REM*****
530 REM **C40=4 CHANNEL STRING OUTLET CONC**CI=ALL CHANNEL INLET CONC*****
540 REM*****NEED FILES FOR C40,C70,C80,C90,C100,C110,C120,CTST0,CI*****
550 REM *****
560 PRINT "INITIALIZING FILES"
565 INPUT "ARE THE FILES INITIALIZED? 1 FOR YES, 0 FOR NO" ;DUM: IF DUM =1 THEN
940:IF DUM = 0 THEN 567 ELSE 565
567 REM *****WRITE THE INITIAL CONC TO THE FILES FOR TIMES UP TO THE 12 CH
      STRING RESIDENCE TIME*****
570 OPEN "R",#1,"CTST1A0",15 :GOSUB 880
580 OPEN "R",#1,"CTST1B0",15 :GOSUB 880
590 OPEN "R",#1,"CTST1C0",15 :GOSUB 880
600 OPEN "R",#1,"CTST1D0",15 :GOSUB 880
610 OPEN "R",#1,"CTST1E0",15 :GOSUB 880
620 OPEN "R",#1,"CTST2A0",15 :GOSUB 880
630 OPEN "R",#1,"CTST2B0",15 :GOSUB 880
640 OPEN "R",#1,"CTST2C0",15 :GOSUB 880
650 OPEN "R",#1,"CTST2D0",15 :GOSUB 880
660 OPEN "R",#1,"CTST2E0",15 :GOSUB 880
670 OPEN "R",#1,"CTST3A0",15 :GOSUB 880
680 OPEN "R",#1,"CTST3B0",15 :GOSUB 880
690 OPEN "R",#1,"CTST3C0",15 :GOSUB 880
700 OPEN "R",#1,"CTST3D0",15 :GOSUB 880
710 OPEN "R",#1,"CTST3E0",15 :GOSUB 880
720 OPEN "R",#1,"CTST4A0",15 :GOSUB 880
730 OPEN "R",#1,"CTST4B0",15 :GOSUB 880
740 OPEN "R",#1,"CTST4C0",15 :GOSUB 880
750 OPEN "R",#1,"CTST4D0",15 :GOSUB 880
760 OPEN "R",#1,"CTST4E0",15 :GOSUB 880
770 OPEN "R",#1,"C40",15 :GOSUB 880
780 OPEN "R",#1,"C70",15 :GOSUB 880
790 OPEN "R",#1,"C80",15 :GOSUB 880
800 OPEN "R",#1,"C90",15 :GOSUB 880
810 OPEN "R",#1,"C100",15 :GOSUB 880
820 OPEN "R",#1,"C110",15 :GOSUB 880
830 OPEN "R",#1,"C120",15 :GOSUB 880
870 GOTO 930
880 FIELD#1,5 AS WHEN$,10 AS C$
890 T=0:RECNO=1
900 LSET WHEN$=MK$(T):LSET C$=MK$(INITCONC):PUT #1,RECNO
910 RECNO=RECNO+1:T=T+1:IF T<RT12X THEN 900
920 CLOSE #1:RETURN
930 REM

```

```

940 REM *****FILE FOR STORING THE INLET CONCENTRATION=CI*****
950 REM *****CI RESULTS FROM MIXING THE CHANNELS OUTLET CONCS*****
960 OPEN "O",#2,"MODL4T3.PRN"
970 T=0
980 RECNO=T+1
985 REM *****READ THE FILES FOR THE CONCS AT TIME T*****
1140 OPEN "R",#1,"CTST4AO",15 :GOSUB 1260: CTST4AO=CC
1150 OPEN "R",#1,"CTST4BO",15 :GOSUB 1260: CTST4BO=CC
1160 OPEN "R",#1,"CTST4CO",15 :GOSUB 1260: CTST4CO=CC
1170 OPEN "R",#1,"CTST4DO",15 :GOSUB 1260: CTST4DO=CC
1180 OPEN "R",#1,"CTST4EO",15 :GOSUB 1260: CTST4EO=CC
1185 OPEN "R",#1,"C4O",15 :GOSUB 1260: C4O=CC
1190 OPEN "R",#1,"C7O",15 :GOSUB 1260: C7O=CC
1200 OPEN "R",#1,"C8O",15 :GOSUB 1260: C8O=CC
1210 OPEN "R",#1,"C9O",15 :GOSUB 1260: C9O=CC
1220 OPEN "R",#1,"C10O",15 :GOSUB 1260: C10O=CC
1230 OPEN "R",#1,"C11O",15 :GOSUB 1260: C11O=CC
1240 OPEN "R",#1,"C12O",15 :GOSUB 1260: C12O=CC
1243 REM USE THE NEXT STATEMENT IF THE FILE NEEDS CHECKING
1245 REM PRINT "T=",T:PRINT "CTST4AO=",CTST4AO,CTST4BO,CTST4CO,CTST4DO,CTST4EO:
PRINT "C4O=",C4O,C7O,C8O,C9O,C10O,C11O,C12O:T=T+1:GOTO 980
1250 GOTO 1280
1260 FIELD#1,5 AS WHEN$,10 AS C$
1270 GET #1,RECNO:CC=CVS(C$):CLOSE #1:RETURN
1280 REM *****CALCULATE INLET CONC AT DP METER AT TIME T*****
1290 CI=(N4*C4O+N7*C7O+N8*C8O+N9*C9O+N10*C10O+N11*C11O+N12*C12O)*CHFLOW+(CTST4AO
+CTST4BO+CTST4CO+CTST4DO+CTST4EO)*(TSTCHFLOW+INJFLOW)/5
1300 CI=CI/(47*CHFLOW+TSTCHFLOW+INJFLOW)

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1310 REM*****PREDICT TEST STRING CHANNEL 1 EXIT CONC AT A TIME WHICH IS T+RT IN
THE FUTURE*****
1320 CTST1A0=(C1*TSCHFLOW+INJRAT/20*22.4/60*101.325/PAVG*TAUG/273.2)/
(INJFLOW+TSCHFLOW)
1330 CTST1B0=(C1*TSCHFLOW+INJRAT/20*22.4/60*101.325/PAVG*TAUG/273.2)/
(INJFLOW+TSCHFLOW)
1340 CTST1C0=(C1*TSCHFLOW+INJRAT/20*22.4/60*101.325/PAVG*TAUG/273.2)/
(INJFLOW+TSCHFLOW)
1350 CTST1D0=(C1*TSCHFLOW+INJRAT/20*22.4/60*101.325/PAVG*TAUG/273.2)/
(INJFLOW+TSCHFLOW)
1360 CTST1E0=(C1*TSCHFLOW+INJRAT/20*22.4/60*101.325/PAVG*TAUG/273.2)/
(INJFLOW+TSCHFLOW)
1370 OPEN "R",#1,"CTST1A0",15:TT=T+RTTSTAX:CC=CTST1A0:GOSUB 1790
1380 OPEN "R",#1,"CTST1B0",15:TT=T+RTTSTBX:CC=CTST1B0:GOSUB 1790
1390 OPEN "R",#1,"CTST1C0",15:TT=T+RTTSTCX:CC=CTST1C0:GOSUB 1790
1400 OPEN "R",#1,"CTST1D0",15:TT=T+RTTSTDX:CC=CTST1D0:GOSUB 1790
1410 OPEN "R",#1,"CTST1E0",15:TT=T+RTTSTEX:CC=CTST1E0:GOSUB 1790
1420 REM *****CALC CONC EX SECOND CHANNEL*****
1430 CTST2A0=(CTST1A0+CTST1B0+CTST1C0+CTST1D0+CTST1E0)/5
1431 CTST2B0=(CTST1A0+CTST1B0+CTST1C0+CTST1D0+CTST1E0)/5
1432 CTST2C0=(CTST1A0+CTST1B0+CTST1C0+CTST1D0+CTST1E0)/5
1433 CTST2D0=(CTST1A0+CTST1B0+CTST1C0+CTST1D0+CTST1E0)/5
1434 CTST2E0=(CTST1A0+CTST1B0+CTST1C0+CTST1D0+CTST1E0)/5
1440 OPEN "R",#1,"CTST2A0",15:TT=T+RTTSTCX+RTTSTAX:CC=CTST2A0:GOSUB 1790
1450 OPEN "R",#1,"CTST2B0",15:TT=T+RTTSTCX+RTTSTBX:CC=CTST2B0:GOSUB 1790
1460 OPEN "R",#1,"CTST2C0",15:TT=T+RTTSTCX+RTTSTCX:CC=CTST2C0:GOSUB 1790
1470 OPEN "R",#1,"CTST2D0",15:TT=T+RTTSTCX+RTTSTDX:CC=CTST2D0:GOSUB 1790
1480 OPEN "R",#1,"CTST2E0",15:TT=T+RTTSTCX+RTTSTEX:CC=CTST2E0:GOSUB 1790
1490 REM *****CALC CONC EX THIRD CHANNEL*****
1500 CTST3A0=(CTST2A0+CTST2B0+CTST2C0+CTST2D0+CTST2E0)/5
1510 CTST3B0=(CTST2A0+CTST2B0+CTST2C0+CTST2D0+CTST2E0)/5
1520 CTST3C0=(CTST2A0+CTST2B0+CTST2C0+CTST2D0+CTST2E0)/5
1530 CTST3D0=(CTST2A0+CTST2B0+CTST2C0+CTST2D0+CTST2E0)/5
1540 CTST3E0=(CTST2A0+CTST2B0+CTST2C0+CTST2D0+CTST2E0)/5
1550 OPEN "R",#1,"CTST3A0",15:TT=T+RTTSTCX+RTSTCX+RTTSTAX:CC=CTST3A0:GOSUB 1790
1560 OPEN "R",#1,"CTST3B0",15:TT=T+RTTSTCX+RTSTCX+RTTSTBX:CC=CTST3B0:GOSUB 1790
1570 OPEN "R",#1,"CTST3C0",15:TT=T+RTTSTCX+RTSTCX+RTTSTCX:CC=CTST3C0:GOSUB 1790
1580 OPEN "R",#1,"CTST3D0",15:TT=T+RTTSTCX+RTSTCX+RTTSTDX:CC=CTST3D0:GOSUB 1790
1590 OPEN "R",#1,"CTST3E0",15:TT=T+RTTSTCX+RTSTCX+RTTSTEX:CC=CTST3E0:GOSUB 1790
1600 REM *****CALC CONC EX FOURTH CHANNEL*****
1610 CTST4A0=(CTST3A0+CTST3B0+CTST3C0+CTST3D0+CTST3E0)/5
1620 CTST4B0=(CTST3A0+CTST3B0+CTST3C0+CTST3D0+CTST3E0)/5
1630 CTST4C0=(CTST3A0+CTST3B0+CTST3C0+CTST3D0+CTST3E0)/5
1640 CTST4D0=(CTST3A0+CTST3B0+CTST3C0+CTST3D0+CTST3E0)/5
1650 CTST4E0=(CTST3A0+CTST3B0+CTST3C0+CTST3D0+CTST3E0)/5
1660 OPEN "R",#1,"CTST4A0",15:TT=T+3*RTTSTCX+RTTSTAX:CC=CTST4A0:GOSUB 1790
1670 OPEN "R",#1,"CTST4B0",15:TT=T+3*RTTSTCX+RTTSTBX:CC=CTST4B0:GOSUB 1790
1680 OPEN "R",#1,"CTST4C0",15:TT=T+3*RTTSTCX+RTTSTCX:CC=CTST4C0:GOSUB 1790
1690 OPEN "R",#1,"CTST4D0",15:TT=T+3*RTTSTCX+RTTSTDX:CC=CTST4D0:GOSUB 1790
1700 OPEN "R",#1,"CTST4E0",15:TT=T+3*RTTSTCX+RTTSTEX:CC=CTST4E0:GOSUB 1790
1710 OPEN "R",#1,"C40",15:TT=T+RT4X:CC=C1:GOSUB 1790
1720 OPEN "R",#1,"C70",15:TT=T+RT7X:CC=C1:GOSUB 1790
1730 OPEN "R",#1,"C80",15:TT=T+RT8X:CC=C1:GOSUB 1790
1740 OPEN "R",#1,"C90",15:TT=T+RT9X:CC=C1:GOSUB 1790
1750 OPEN "R",#1,"C100",15:TT=T+RT10X:CC=C1:GOSUB 1790
1760 OPEN "R",#1,"C110",15:TT=T+RT11X:CC=C1:GOSUB 1790
1770 OPEN "R",#1,"C120",15:TT=T+RT12X:CC=C1:GOSUB 1790
1780 GOTO 1800
1790 FIELD#1,5 AS WHENB,10 AS CB:RECNO=TT+1:LSBT WHENB=MK5B(TT):LSBT CB=MK5B(CC)
:PUT #1,RECNO:CLOSE #1:RETURN

```

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1800 REM *****RECALCULATE CONC IN MICROLITRE 920/L (920*CS2)*****
1810 COUTLET=C1/(1+C1)*1000000
1820 REM *****CHECK FOR CONDENSATION IN THE TEST CHANNEL*****
1830 CTSTCH=CTST1AQ/(1+CTST1AQ)*1000000:PB20=CTSTCH/1000000*PAVG*1000
1840 PRINT T,COUTLET,CTSTCH,PB20
1850 PRINT#2,T,COUTLET
1860 IF PB20>2000 THEN PRINT "CONDENSATION WILL OCCUR IN THE TEST CHANNEL IF THE
      TEMPERATURE DROPS BELOW 20 DEG C":IF PB20>2000 THEN 1880
1870 T=T+1:GOTO 980
1880 REM*****CSTR ESTIMATE*****
1890 CSTRCONC1255=255*IN/RAT/20*22.4/60*101.325/PAVG*TAVG/273.2*1000000/((CHVOL*
      480)+1000000*INITCONC/(1+INITCONC))
1900 PRINT 255,CSTRCONC1255
1910 PRINT#2,255,CSTRCONC1255
1920 CLOSE#2
1930 STOP

```

DARLINGTON AGS TESTS

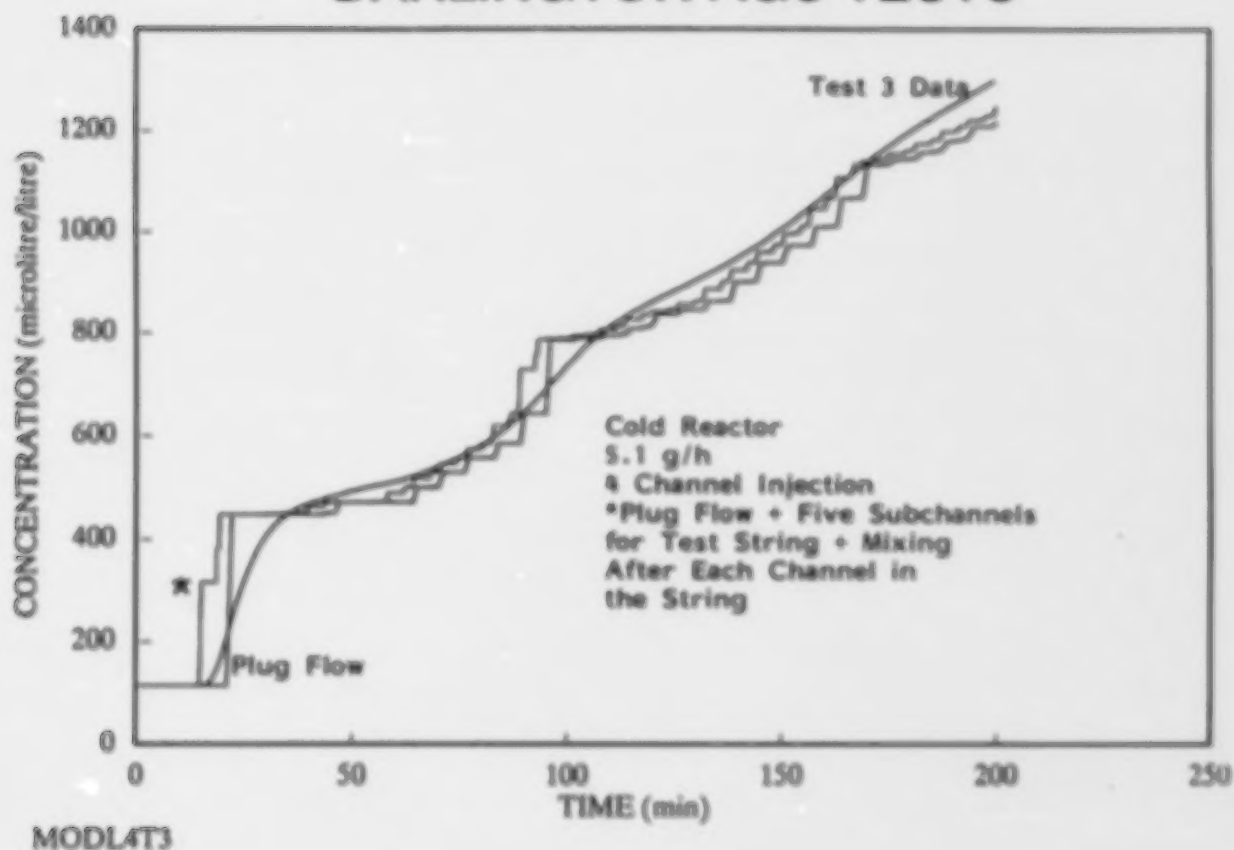


FIGURE F-4

DIVIDING THE TEST CHANNEL INTO FIVE SUBCHANNELS OF
EQUAL FLOW RATE AND ALLOWING MIXING AFTER EACH
CHANNEL IN THE TEST STRING RESULTS IN AN EARLIER SIGNAL